

COLLECTION AND ANALYSIS OF WIND SPEED PROVISIONS IN
CODES AND STANDARDS FOR WIND-RESISTANT DESIGN OF
BUILDINGS IN 195 COUNTRIES

A DISSERTATION
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ABSTRACT

Not many disaster management projects related to strong winds had been conducted in the realm of international cooperation. This study collected and analyzed laws, regulations, codes, and standards for wind-related disasters in 195 countries and discussed the big picture of the world to understand these situations and issues from the aspect of wind-resistant design of buildings. Additionally, the potential for inconsistencies among reference wind speeds in national border areas had been a subject of discussion at International Workshops on Regional Harmonization of Wind Loading and Wind Environmental Specifications in Asia-Pacific Economies (APEC-WW). This study also explored a unified approach to practically compare reference wind speeds in national border areas to clarify the details of this issue.

Initially, we collected and analyzed a substantial amount of information from 195 countries, considering three levels of jurisdictional areas: countries (first level), states or provinces (second level), and cities (third level). In this phase, we gathered online information through Google Search and conducted email interviews with consultants, researchers, and officials as needed, and fully utilized Google Translate to understand the information obtained. Furthermore, we underwent a process of trial and error in three phases: 1) obtaining relevant information from other countries, 2) correctly scanning the contents of the information, and 3) accurately understanding them. Afterward, we summarized the status of the development, enforcement, or administration of laws, regulations, codes, and standards for each country. Our country overviews revealed that 1) 137 countries had legal and regulatory frameworks, including provisions on wind-resistant design of buildings, 2) developed countries did not always have regulations for this purpose, 3) developing countries did not always establish legal and regulatory frameworks akin to those of closely related developed countries, and 4) some countries incorporated these provisions into regulations for seismic-resistant design of buildings.

Subsequently, we discussed the worldwide status on legal and regulatory frameworks from the perspective of three types of provisions: wind-resistant design liability, wind load calculation methods, and reference wind speeds or pressures. Our studies of these frameworks revealed that 1) 137 countries mentioned or implied wind-resistant design liability, with 121 and 115 of these countries defining wind load calculation methods and reference wind speeds or pressures, respectively, 2) 110 and 27 countries mentioned or implied wind-resistant design liability at the national and subnational levels, respectively, 3) 16 countries only mentioned or implied wind-resistant design liability, and 4) another set of 16 countries accepted multiple wind load calculation methods or multiple reference wind speeds or pressures. Our analyses of human and economic damage from storms, as well as the economic development of countries, suggested that the establishment of such frameworks 1) was slightly influenced by human damage from storms, 2) was not necessarily affected by economic damage from storms, and 3) required a level of economic development at least equivalent to the lower-middle-income bracket. Additionally, considering the limited number of national or subnational initiatives toward the establishment of these frameworks in 58 countries that currently lacked them, it was expected that the number of countries with these frameworks would continue to increase gradually, rather than dramatically.

Then, we discussed worldwide trends of 176 codes and standards adopted in 190 countries, focusing on three components modeling atmospheric boundary layers: wind speed profile, turbulence intensity

profile, and turbulence spectrum with turbulence scale. We classified atmospheric boundary layer models into 22 subcategories based on their country or international organization of origin, and further grouped them into three categories based on their extent of spread to other regions or countries: Worldwide (WW), Regional (RG), and Domestic (DS) models. The subcategories included Australian (AU), Bajan (BD), Brazilian (BR), Canadian (CA), Dutch (NL), European Union (EU), French (FR), German (DE), Indian (IN), International Organization for Standardization (IO), Italian (IT), Japanese (JP), Mexican (MX), Peruvian (PE), Portuguese (PT), Russian (RU), South African (ZA), Swiss (CH), United Kingdom (UK), United States (US), Former Yugoslavian (YU), and Domestic (DS) models. Our analysis of these subcategories indicated that two models: EU and US were the most widely accepted worldwide, being adopted in 43 countries, accounting for 22.1% of the total. They were followed by four models: UK, FR, AU, and RU, with their respective adoption numbers being 25, 25, 13, and 12. Furthermore, considering regional or national initiatives toward the development of codes or standards, it was expected that the EU and US models would supersede some of the other existing models and become more influential in the future.

Lastly, we explored a unified approach for practically comparing reference wind speeds in national border areas, while ensuring respect for atmospheric boundary layer models defined in laws, regulations, codes, and standards of each country to enhance the effectiveness of this initiative. This approach involved the theory of deriving the statistical distribution of the maxima of a stationary random function. After reviewing the theory applied to averaging time conversions of wind speeds and classifying 113 codes and standards into 37 representative groups based on atmospheric boundary layer models, we computed peak factors for obtaining wind speeds with various averaging times for 11 combinations of turbulence spectra and sampling lengths. Our computational results allowed us to effortlessly convert wind speeds into different specifications using only wind speeds and turbulence scales. We then calculated wind speed conversion factors for the 37 representative groups as a practical application example, considering some differences in reference wind speed specifications. Our calculational results confirmed the adequacy of our discussed approach as a unified approach due to its broad applicability, as well as the significance of comparing reference wind speeds in national border areas, respecting different specifications from country to country, such as terrain roughness or heights above ground.

This thesis will serve as a valuable reference for countries and regions with incomplete laws, regulations, codes, or standards in moving forward with establishing more complete ones. It will also facilitate the conversion of wind speeds into various specifications using the discussed approach. Additionally, this thesis will provide information on the details of inconsistency in reference wind speeds in national border areas and contribute to the development of a world map of wind speeds, in line with resolutions passed at APEC-WW. Furthermore, we believe that this series of studies will clarify legal or technical issues related to wind-resistant design of buildings and contribute to the development of disaster management projects for strong winds, which require international cooperation.

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1 INTRODUCTION

In this chapter, we clarify the issues and problems to be discussed in this thesis through literature reviews from four perspectives: 1) international cooperation for wind-related disaster risk reduction, 2) legal and regulatory frameworks including provisions on wind-related disasters, 3) codes and standards related to wind-resistant design of buildings, and 4) reference wind speeds for wind-resistant design of buildings. Then, we set the final goals of this study, state the overall purpose and specific objectives of this thesis, describe the originality and value of this thesis, and outline the structure and scope of this thesis.

1.1 Literature Reviews

1.1.1 International cooperation for wind-related disaster risk reduction

Due to the effects of economic development, urbanization and climate change worldwide, economic damage caused by disasters is rising compared to the number of disasters or human damage. According to the report (GFDRR/ODI 2013) released by the Global Facility for Disaster Risk Reduction and Recovery (GFDRR) and the Overseas Development Institute (ODI), disaster-related international cooperation projects did not take a high priority in the 1990s. However, due to a sudden increase in disasters worldwide after the 1990s, financing for disaster-related international cooperation increased year by year and reached USD 107 billion in the 20 years from 1991 to 2010. The breakdown was 1) emergency response: USD 70 billion, 2) reconstruction and rehabilitation: USD 24 billion, and 3) disaster risk reduction (DRR): USD 14 billion. Of these, however, the financing for DRR accounted for only 13% of the total and about 0.4% of all financing for international cooperation projects.

In these situations, the Japan International Cooperation Agency (JICA) has proactively been supporting DRR for recipient countries based on lessons learned and recommendations practiced in Japan. Figure 1.1 shows the breakdown of direct DRR support from various donors over the 20 years from 1991 to 2010. (GFDRR/ODI 2013) This figure revealed that Japan was by far the largest single direct donor to DRR in the world, with an amount of USD 3,749 million, accounting for 64% of the total. This reached over eight times more than the second-largest donor, the European Community (USD 480 million), and doubled the amount contributed by all other donors combined. Furthermore, at the third UN World Conference on Disaster Risk Reduction held in Sendai in 2015, the Japanese government announced the Sendai Cooperation Initiative for DRR, which committed to DRR cooperation totaling USD 4 billion and training 40,000 officials from 2015 to 2018. As described above, Japan has led the world in DRR as a top donor.

For DRR projects conducted from fiscal year (FY) 2006 through FY 2015 by JICA, the total amount of three schemes: 1) budget spent on technical cooperation involving DRR, 2) the JICA-implemented supervision and promotion portion of grant aid projects, and 3) paid Japanese yen loans was JPY 604 billion, excluding JPY 2.9 billion for non-regional technical cooperation. (JICA 2017) Figure 1.2 shows the breakdown of DRR support conducted by JICA in the same period for each type of disaster. In descending order, JPY 286 billion (47%), JPY 75 billion (12%), JPY 55 billion (9.1%), and JPY 42 billion (7.0%) were allocated for flood-related projects, comprehensive DRR-related projects, earthquake-related projects, and meteorological observation projects, respectively. Only JPY 9.4 billion (1.6%) was allocated for wind-related (typhoon, cyclone, or hurricane) projects. Even when combined with meteorological observation projects, it totaled only JPY 52 billion (5%). However, this fact does not necessarily imply that typhoons, cyclones, or hurricanes are less significant than earthquakes or floods. Figure 1.3 to Figure 1.5 show annual averages of occurrence, human loss, or economic loss for each type of disaster from 2001 to 2020. (CRED 2022) Although these averages due to storms are not always limited to disasters caused by strong winds, storms accompanied by them should be considered serious from any perspective. As a matter of fact, international cooperation projects related to storms have been implemented in regions such as the

Caribbean and Asia-Pacific. Table 1.1 lists some projects related to wind-resistant design of buildings. The most influential projects were implemented in the Caribbean region. One such project, undertaken by the Association of Caribbean States (ACS) with financial assistance from the Government of Italy, aimed to update wind loading codes or standards. (ACS 2003) This project analyzed the situation of codes or standards at the time in the ACS member countries and drafted the model code based on one of the American Society of Civil Engineers (ASCE) standards. Other projects, undertaken by the Pan American Health Organization (PAHO) with financial support from the Federal Government of the United States or the Government of Canada, developed wind hazard maps primarily for the CARICOM Regional Organisation for Standards and Quality (CROSQ). (PAHO 2008, 2019) The Asian Disaster Preparedness Center (ADPC) implemented projects to develop wind hazard maps in at least two countries: Laos and Timor-Leste, with fundings from the United Nations Development Programme (UNDP). (ADPC 2010, 2012) UNDP also developed a wind hazard map in Maldives. (UNDP 2006) Similarly, JICA has implemented various projects related to typhoons, cyclones, or hurricanes in recipient countries. However, only a few deliverables have provided nationally applicable standards for wind-resistant design of structures, such as statistically analyzed wind speeds for the design of power transmission systems in Laos (JICA 2002).

At any rate, it is unclear why financing for wind-related disasters was very low globally. To determine the cause, it is meaningful to examine the following possible factors from legal, institutional, technical, or financial aspects:

- (1) national or subnational governments did not prioritize legally regulating wind-resistant design of buildings due to low human or economic damage experienced;
- (2) national or subnational governments could not develop codes or standards for wind-resistant design of buildings due to a lack of financing or skill;
- (3) national or subnational governments could not establish a system to legally regulate wind-resistant design of buildings due to a lack of financing or skill; and
- (4) officials or consultants in the concerned countries concerned could not apply codes or standards for wind-resistant design of buildings in practice due to a lack of specialized education or technical training.

Furthermore, it is significant to discuss international cooperation regarding wind-related disasters through these considerations.

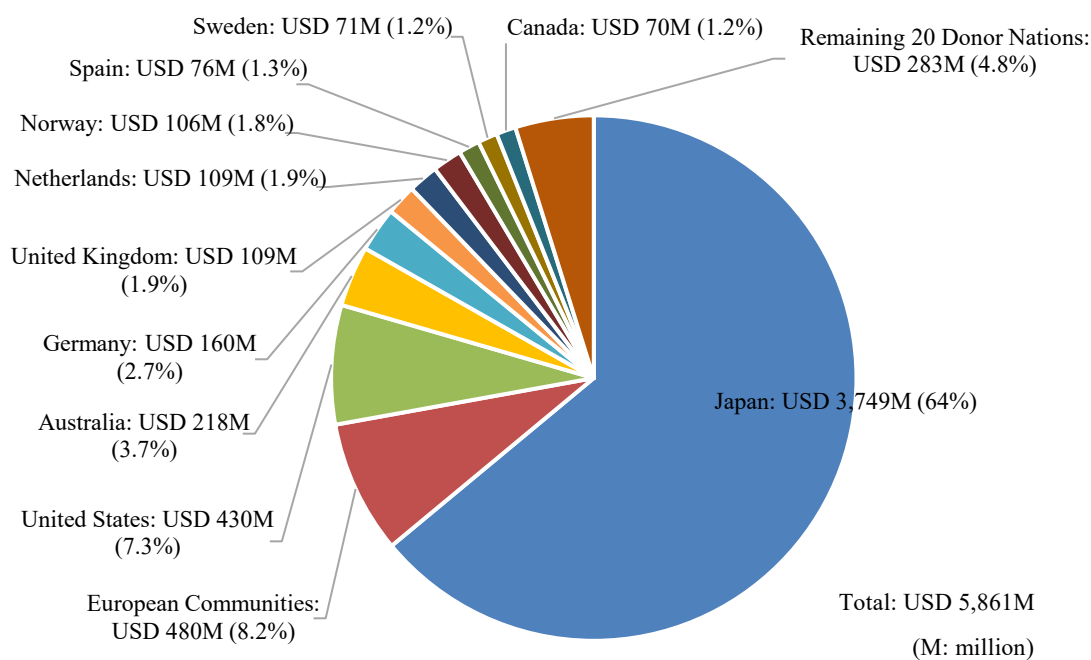


Figure 1.1 DRR support from various donors from 1991 to 2010

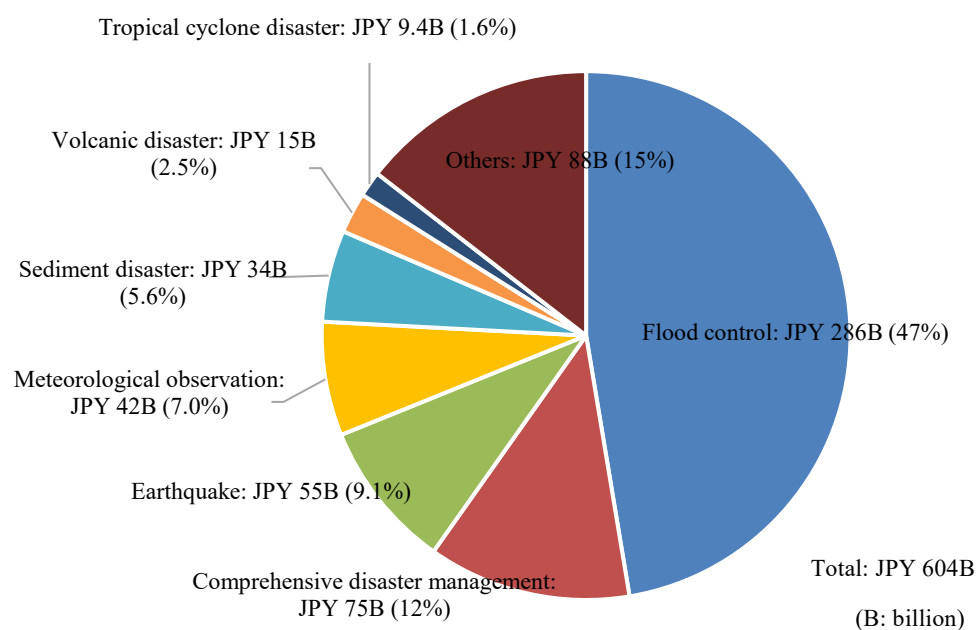


Figure 1.2 DRR support conducted by JICA from FY 2006 to FY 2015

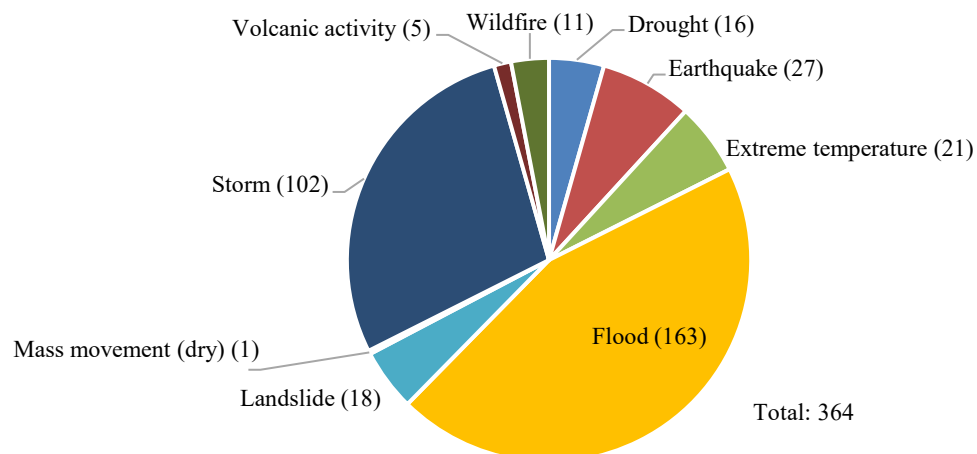


Figure 1.3 Annual average occurrences by disaster type from 2001 to 2020

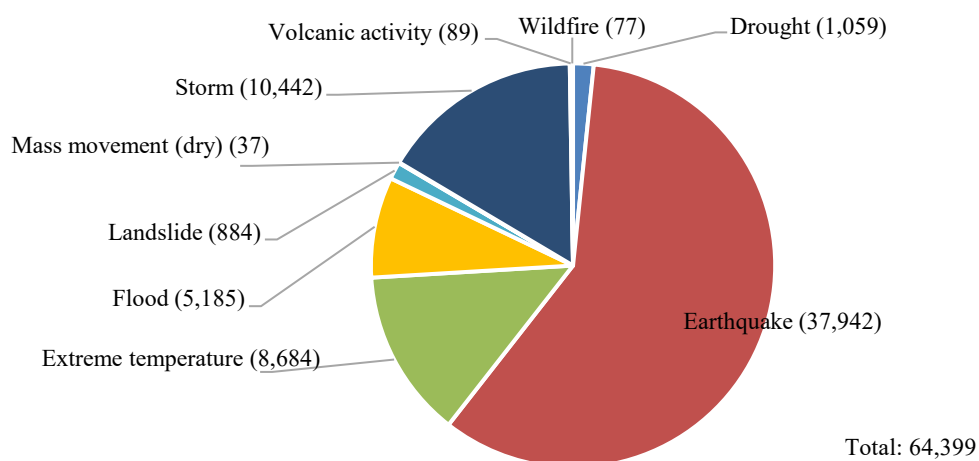


Figure 1.4 Annual average human losses by disaster type from 2001 to 2020

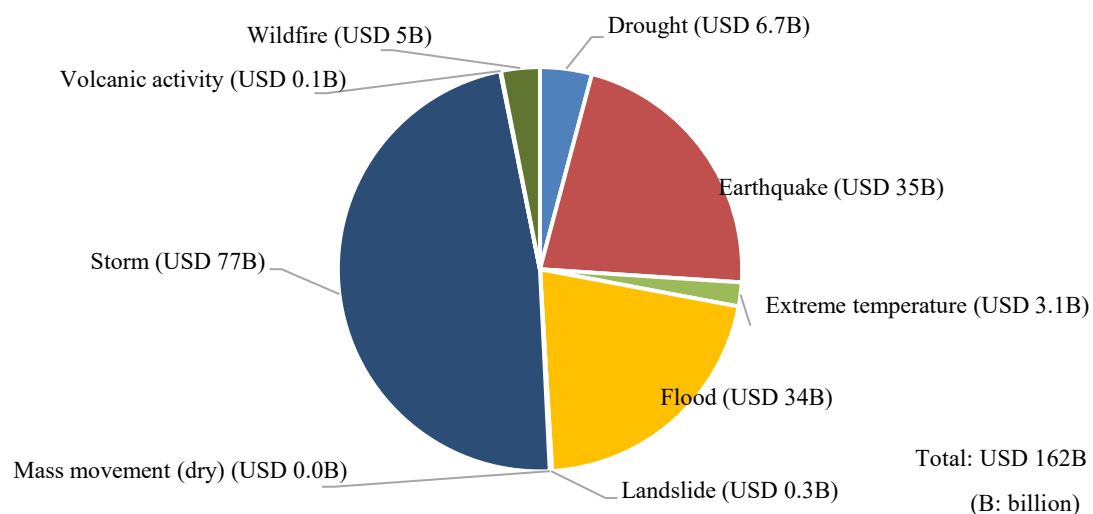


Figure 1.5 Annual average economic losses by disaster type from 2001 to 2020

Table 1.1 Major international cooperation projects related to wind-resistant design of buildings

Organization	Year	Project	Donor	Recipient
ACS	2003	Updating Building Codes of the Greater Caribbean for Winds and Earthquakes	Italy	ACS (25 countries)
PAHO	2008	Development of Design Wind Speed Maps for the Caribbean for Application with the Wind Load Provisions of ASCE 7	United States	CROSQ (15 countries)
	2019	Development of Design Wind Speed Maps for the Caribbean for Application with the Wind Load Provisions of ASCE 7-16 and Later	Canada	
ADPC	2010	Developing a National Risk Profile of Lao PDR	UNDP	Laos
	2012	A Comprehensive National Hazard Assessment and Mapping in Timor-Leste		Timor-Leste
UNDP	2006	Developing a Disaster Risk Profile for Maldives	UNDP	Maldives

1.1.2 Legal and regulatory frameworks including provisions on wind-related disasters

Although construction technologies are still lagging behind economic growth in developing countries, urbanization is proceeding in these countries due to a shift in the global economy. It follows that meteorological disasters, which are hypothesized to be influenced by the effects of climate change (IPCC 2014), and terrestrial disasters, which are said to have entered an active period (Perkins 2011), have been occurring repeatedly in urban areas in recent years. Thus, the early enactment and proper enforcement of laws and regulations are becoming increasingly imperative from the viewpoint of urban risk and crisis management against natural disasters.

Building laws and regulations are crucial legal and regulatory tools for setting minimum requirements for sites, facilities, structures, and uses of buildings to protect secure lives of people who use buildings. They also present a major opportunity for authorities to pursue resource conservation and waste reduction, as well as to manage risks in construction works, which consume large amounts of materials and emit large amounts of greenhouse gases. In addition, they ensure secure environments for workers and serve as guideposts for maintaining and improving the skills of professionals involved in long-term or highly dangerous construction works. As such, since they play crucial roles in socioeconomics, they were frequently studied by international organizations in the early 2010s, especially from legal, regulatory, or institutional aspects.

Table 1.2 lists three valuable projects implemented by international organizations. The United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) and the Asian Institute of Technology (AIT) studied building codes of nine countries inside and outside the Asia-Pacific region. (UNESCAP/AIT 2012) This study evaluated them from the perspectives of 12 elements: six environmental sustainability elements and six disaster resilience elements. It concluded that all of them could effectively address wind-related hazards due to storms or typhoons, as provisions on wind resistance were incorporated into them. Wind resistance against storms or typhoons was also considered as one of the disaster resilience elements. On the other hand, the Asia-Pacific Economic Cooperation (APEC) Secretariat studied how 19 member countries or regions utilized building codes, which aligned with green goals of resource conservation and waste reduction. (APEC 2013) This study summarized approaches for developing, adopting, administering, and enforcing building codes for each country. It recommended that building codes should: 1) embrace best practices, 2) provide efficient options, 3) balance various requirements, 4) have flexibility to meet country-specific requirements, and 5) recognize post-construction impacts. Furthermore, the International Federation of Red Cross and Red Crescent Societies (IFRC) and UNDP studied legal frameworks for DRR in 31 countries. (IFRC/UNDP 2014) This study considered both legislative provisions and stakeholder views. It recommended that legal frameworks for DRR should 1) include institutional mandates, 2) allocate dedicated resources, 3) facilitate participations of communities, civil societies, or vulnerable groups, and 4) establish responsibility and accountability of relevant actors.

As described above, legal and regulatory frameworks associated with the building sector have not been studied from a global standpoint. In other words, laws and regulations that regulate wind-resistant design of buildings have not been studied either from the same standpoint. Therefore, it remains unclear how many countries establish them, and why some countries have not.

Table 1.2 Major comparative studies from legal, regulatory, or institutional aspects

Organization	Year	Project	Number of countries
UNESCAP&AIT	2012	Integrating Environmental Sustainability and Disaster Resilience in Building Codes	9 countries inside or outside the Asia-Pacific region
APEC Secretariat	2013	APEC Building Codes, Regulations, and Standards: Minimum, Mandatory and Green	19 member countries or regions
IFRC&UNDP	2014	Effective law and regulation for disaster risk reduction: a multi-country report	31 countries

1.1.3 Codes or standards related to wind-resistant design of buildings

Setting design loads is one of the most critical tasks in ensuring the structural safety of buildings. The approaches thereto are commonly defined in structural codes or standards, which can consider terrestrial or meteorological phenomena around construction sites and structural characteristics of planned buildings. The most representative example of internationally recognized structural codes or standards is the Eurocodes. The Eurocodes comprise 10 standards that set forth how structural design should be conducted in the European Union (EU) member countries. The International Building Codes (IBCs) and the ASCE standards are also internationally recognized codes and standards, respectively, which are accepted in many countries without national or regional barriers. In the field of wind-resistant design of buildings, codes or standards from Australia, Canada, the United Kingdom, Japan, China, and the International Organization for Standardization (ISO) are also accepted as internationally recognized codes or standards. These codes or standards have been directly cited in laws or regulations of other countries, or have been frequently used as references in developing codes or standards, or as benchmarks for reviewing codes or standards developed. (e.g., Ahmed and Mandal 2017; Ge et al. 2010; Popov 2000)

At the same time, comparative studies of internationally recognized codes and standards have also been conducted regarding wind loads on buildings, as represented in Table 1.3. (Hongo 1986) summarized wind load codes and standards of 24 countries and discussed considerations when applying them. Kijewski and Kareem (1998) compared seven internationally recognized codes and standards through estimations of alongwind, acrosswind, and torsional responses. Additionally, Zhou et al. (2002) assessed the sizable scatter that exists among wind effects estimated by various codes or standards through comparisons of alongwind loads on tall buildings recommended by five of the seven internationally recognized codes and standards. Stathopoulos and Alrawashdeh (2020) discussed similarities and differences among external and internal pressures in three internationally recognized codes and standards and attempted to resolve some of the apparent discrepancies. As an international initiative, the working group set up by the International Association for Wind Engineering (IAWE) discussed important issues relevant to dynamic wind-induced responses for use in five internationally recognized codes and standards and made some recommendations for the harmonization of international codification for wind loads. (Tamura et al. 2005) Furthermore, the working group set up for the International Workshops on Regional Harmonization of Wind Loading and Wind Environmental Specifications in Asia-Pacific Economies (APEC-WW) conducted comparative studies of design wind loads calculated by 15 different codes and standards from the Asia-Pacific region and summarized practical outcomes for low-, medium-, and high-rise buildings. (Holmes et al. 2008; Tamura et al. 2009)

As described above, comparative studies have been conducted based on internationally recognized codes and standards for wind-resistant design of buildings. However, efforts to understand the broader global context in this field have been limited. Consequently, it remains unclear how many codes and standards for wind-resistant design of buildings exist worldwide, and which of these are most widely adopted.

Table 1.3 Major comparative studies from technical aspects: wind loads on buildings

Research group		Year	Number of codes and standards
Hongo		1986	24 codes and standards AS 1170.Part 2-1983 (Australia), ONORM B 4000 3 Teil 1 (Austria), NBC 1980 Part4 (Canada), TJ9-74 (China), CSN 73 0035 JK.1976 (Czechoslovakia), DS 410.2.1977 (Denmark), Regles NV 65.1967 (France), DIN 1055 Teil4.1977 (West Germany), TGL 20 167.Blatt 1.1964 (East Germany), Code of Practice.1983 (Hong Kong), CNR-UNI 10012-67 (Italy), BSLJ (Japan), NEN 3850.TGB 1972 (Netherlands), NZS 4203:1976 (New Zealand), NS 3479.1981 (Norway), PN-82 B-02011 (Poland), Pecreto no.44041.1961 (Portugal), STAS 2843-58 (Romania), NBE-MV 101-1962 (Spain), SBN 1975 21:6 (Sweden), SIA Normes 160.1978 (Switzerland), CP3 Ch.V Part2.1972 (United Kingdom), UBC 1982 (United States), BC&RCII-A 11-62 (Soviet Union)
Univ. of Notre Dame	Kijewski and Kareem	1998	7 codes and standards: ASCE 7-98 (United States), AS 1170.2-89 (Australia), NBC-1995 (Canada), RLB-AIJ-1993 (Japan), Eurocode-1993 (European Union), BS 6399-1995 (United Kingdom), GBJ9 (China)
	Zhou et al.	2002	5 codes and standards: ASCE 7-98 (United States), AS 1170.2-89 (Australia), NBC-1995 (Canada), RLB-AIJ-1993 (Japan), Eurocode-1993 (European Union)
WG in IAWE	Tamura et al.	2005	5 codes and standards: ASCE 7-98 (United States), AS 1170.2:1989 (Australia), NBCC 1995 (Canada), AIJ-RLB-1993 (Japan), ENV 1991-2-4 (1994) (European Union)
WG in APEC-WW	Holmes et al.	2008	15 codes and standards: AS/NZS 1170.2: 2002 (Australia & New Zealand), NBCC (2005) (Canada), GB 50009-2001 (China), CP-2004 (Hong Kong), IS 875(Part 3)-1987 (India), SNI-03-1727 (Indonesia), AIJ-RLB-2004 (Japan), KBC (2005) (South Korea), MS 1553-2002 (Malaysia), NSCP-2001 (Philippines), draft standard (Singapore), TBC (Taiwan, China), EIT-1018-46 (Thailand), ASCE 7-05 (United States), TCVN 2737-1995 (Vietnam)
	Tamura et al.	2009	
Concordia Univ.	Stathopoulos and Alrawashdeh	2020	3 codes and standards: ASCE 7-2016 (United States), NBCC-2015 (Canada), GB 50009-2012 (China)

1.1.4 Reference wind speeds for wind-resistant design of buildings

Reference wind speeds are the most important factors for determining practical design wind loads. They have been developed in unique ways in individual countries, giving rise to the potential for discrepancies in reference wind speeds in national border areas, as exemplified by Figure 1.6 (Hayakawa 2012). Therefore, this issue has repeatedly been discussed at APEC-WW (2007, 2009, 2010, 2012). However, the details have not yet been revealed. On the other hand, the specifications of reference wind speeds differ from country to country, as shown in Figure 1.7 (Hayakawa 2012). Therefore, to practically compare reference wind speeds in national border areas, various averaging times, which are defined in codes or standards for wind-resistant design of buildings, must correspond with each other.

Conversions of wind speed averaging times have been discussed in previous studies, as represented in Table 1.4. Durst (1960) proposed wind speed conversion factors based on statistical analyses of strong wind records over unobstructed flat fields. The curve based on the Durst factors, known as the Durst curve, has been widely referenced in various codes or standards, including the series of the ASCE standards. Miller (2011) reviewed the Durst factors using an expanded data set from the same source used by Durst. Davenport (1964), Hino (1964), Greenway (1979, 1980), Wood (1983), Solari (1993), and Holmes et al. (2014) applied specific turbulence spectra to the statistical distribution of the maxima of a stationary random function (Cartwright 1958; Cartwright and Longuet-Higgins 1956; Rice 1952) and proposed wind speed conversion factors. The Engineering Sciences Data Unit (ESDU) (2002) summarized the full derivation approach to wind speed conversion factors based on Greenway's and Wood's equations. Then, Kwon and Kareem (2014) concluded that the slight discrepancy between the Solari and ESDU factors might be due to difference in wind spectral models and approximation methods, as well as the difference between the Durst factors and the Solari and ESDU factors might in part be due to different averaging schemes. Furthermore, the World Meteorological Organization (WMO) (2010) proposed wind speed conversion factors under tropical cyclone conditions. Taking these findings together, at least averaging schemes, statistical analysis methods, probability distributions, turbulence spectral types, storm types, approximation methods, and terrain situations should be considered when studying reference wind speeds in national border areas.

As described above, discrepancies in reference wind speeds in national border areas have yet to be revealed. On the contrary, a unified approach for practically converting wind speeds into different specifications has not been discussed. Additionally, no practical considerations have been discussed for comparisons of reference wind speeds in national border areas, while ensuring respect for atmospheric boundary layer models in laws, regulations, codes, and standards of each country.

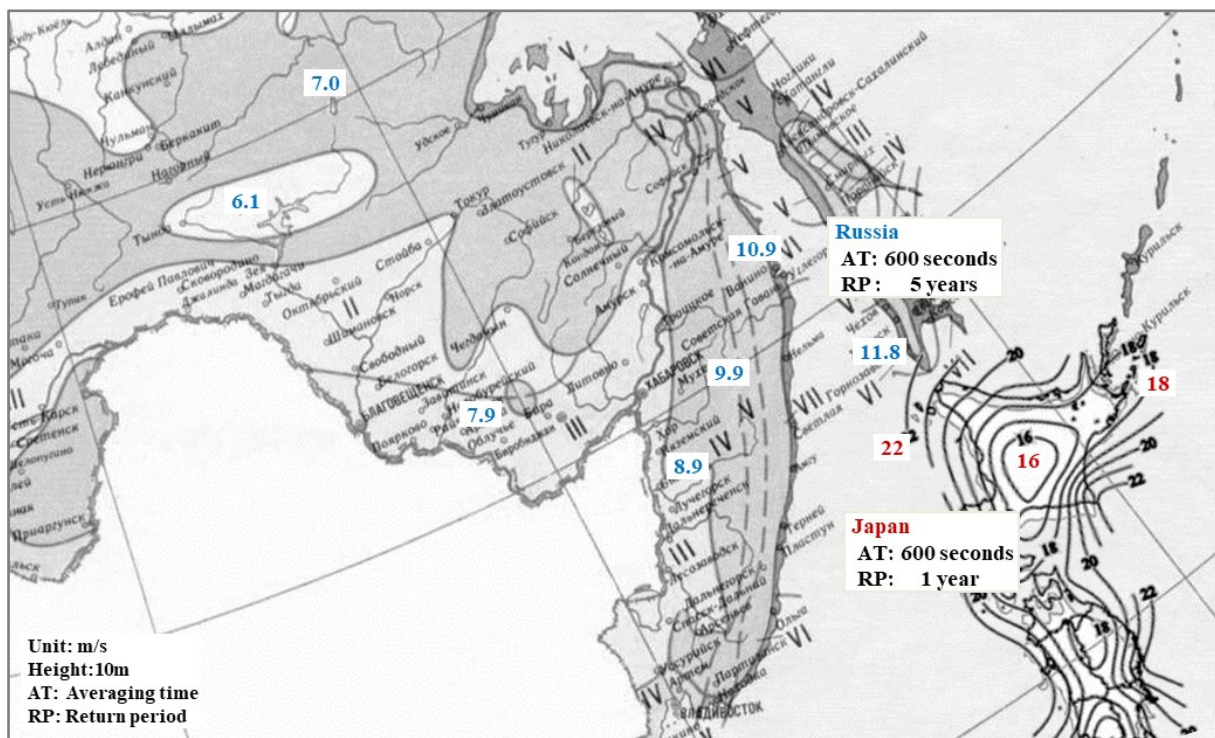


Figure 1.6 Reference wind speeds for Russia and Japan

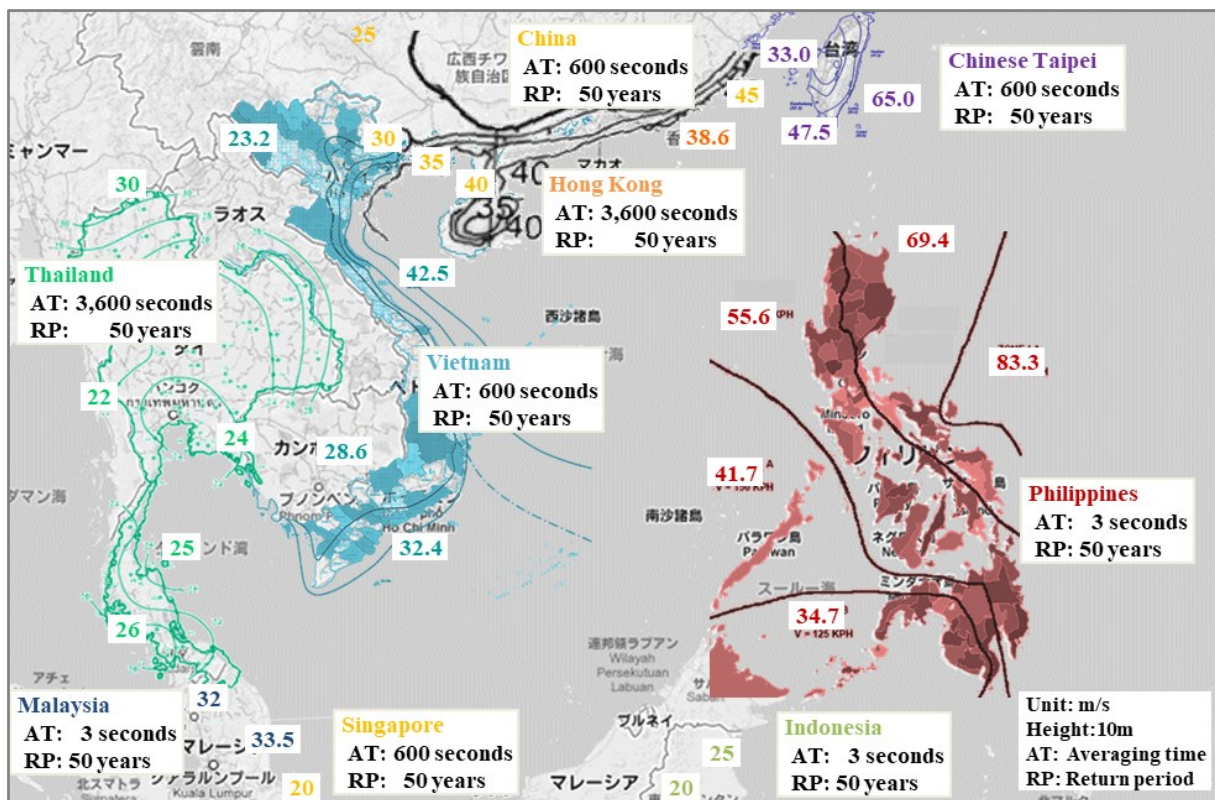


Figure 1.7 Reference wind speeds in Eastern Asia and South-eastern Asia

Table 1.4 Major studies in conversions of wind speed averaging time

Researcher/ Research group	Year	Accomplishments or main findings
Durst	1960	- calculated the reduced variate value of a standard normal distribution using strong wind records over unobstructed flat field.
Miller	2011	- calculated the expected maximum variate value from order statistics given a standard normal distribution as a parent distribution using an expanded data set from the same data source used by Durst. - found that the result calculated by Durst provides a reasonably good match to the result calculated by Miller.
Davenport	1964	- applied the empirical spectral model proposed by Davenport to the statistical distribution of the maxima of a stationary random function.
Hino	1964	
Greenway	1979	- applied the empirical spectral model proposed by Karman to the statistical distribution of the maxima of a stationary random function.
Wood	1980	
Solari	1983	- applied the empirical spectral model proposed by Kaimal to the statistical distribution of the maxima of a stationary random function.
ESDU	1993	- summarized the full derivation approach based on Greenway and Wood.
WMO	2002	- applied the approach summarized by ESDU to tropical cyclone conditions.
Kwon and Kareem	2010	- concluded that the difference between Solari and ESDU may be due to different wind spectral models and approximation methods. - concluded that the difference between Durst and both Solari and ESDU may in part be due to different averaging schemes.
Holmes et al.	2014	- applied the approach organized by ESDU. - concluded that the result calculated by Durst are applicable to a particular longitudinal turbulence intensity.

1.2 Final Goals, Overall Purpose and Specific Objectives

Based on such literature reviews, the final goals of this study, as well as the overall purpose and specific objectives of this thesis, are determined as below.

(1) Final goals of the study

The final goals of this study are:

- to study reference wind speeds in national border areas,
- to develop a world map based on those reference wind speeds, and
- to identify technical challenges in wind-related disasters that require cooperation between neighboring countries, if necessary.

(2) Overall purpose of the thesis

The overall purpose of this thesis is to explore a unified approach applicable to practically comparing reference wind speeds in national border areas, while ensuring respect for laws, regulations, codes, and standards utilized in countries around the world to enhance the effectiveness of this initiative.

(3) Specific objectives of the thesis

The specific objectives of this thesis are:

- to clarify the issues and problems to be discussed in this thesis through literature reviews on international cooperation in the field of wind-resistant design of buildings (Chapter 1),
- to summarize worldwide information on legal and regulatory frameworks, including provisions on wind-resistant design of buildings, as well as codes and standards for wind-resistant design of buildings (Chapter 2),
- to reveal the worldwide status on legal and regulatory frameworks, including provisions on wind-resistant design of buildings, and to discuss challenges in establishing them (Chapter 3),
- to reveal worldwide trends of codes and standards for wind-resistant design of buildings and to discuss future trends (Chapter 4), and
- to review the theory for computing peak factors for obtaining wind speeds with various averaging times, and to discuss practical considerations in comparisons of reference wind speeds in national border areas through practical application examples (Chapter 5).

Additionally, we assumed the following hypotheses for the above objectives at the beginning of this study.

- Obtaining information on legal and regulatory frameworks, as well as codes or standards in countries worldwide while staying in Japan is very challenging. It is necessary to enlist the support of consultants, researchers, or officials from each country. (Chapter 2)
- All countries define provisions on at least wind-resistant design liability within their own legal and regulatory frameworks. Countries that have experienced significant human or economic damage from

storms enforce laws or regulations on both wind load calculation methods and reference wind speeds or pressures. Developing countries establish them but do not properly enforce them, leading to human or economic damage from storms. (Chapter 3)

- Most countries develop their own codes or standards based on the internationally recognized codes or standards. Those of the United States, the European Union or the United Kingdom are more widely consulted worldwide than any other code or standard. (Chapter 4)
- Peak factors or wind speed conversion factors vary significantly, respecting formulae or figures defined in laws, regulations, codes, or standards of each country. This significantly affects the comparison results of reference wind speeds in national border areas. (Chapter 5)

1.3 Originality and Value

(1) Originality of the thesis

This thesis is highly strategic, vital, and unique in the subject of wind-resistant design of buildings because of the following specific initiatives.

- It focuses on legal and regulatory frameworks and discusses the worldwide status of legal and regulatory frameworks, not to mention worldwide trends of codes and standards.
- It explores a unified approach for obtaining wind speeds with various averaging times, while ensuring respect for formulae or figures defined in laws, regulations, codes, or standards, instead of analyzing observational data.

(2) Value of the thesis

This thesis is valuable because of the following expected outcomes.

- The identified worldwide status serves as a valuable reference for countries and regions with incomplete legal and regulatory frameworks and aids them in establishing more complete ones.
- The concluded worldwide trends serve as a valuable reference for countries and regions with incomplete code and standard systems and assist them in developing more complete ones.
- The concluded worldwide trends act as a valuable compass for determining the necessary education and training of human resources in the field of wind-resistant design of buildings.
- The discussed approach enables effortless conversions of wind speeds into different specifications.
- The discussed approach assists in figuring out differences in reference wind speeds in national border areas.
- The discussed approach aids in developing a world map based on reference wind speeds, while respecting codes or standards of each country.
- The challenging initiatives undertaken further promote collaborations between neighboring countries to solve technical challenges in setting reference wind speeds.

1.4 Structure and Scope

(1) Structure of the thesis

Table 1.5 shows the structure of chapters and sections of this thesis. This thesis has six chapters.

Chapter 1: Introduction

We clarify the issues and problems to be discussed in this thesis (Section 1.1), set the final goals of the study, state the overall purpose and specific objectives of this thesis (Section 1.2), describe the originality and value of this thesis (Section 1.3), and outline the structure and scope of this thesis (Section 1.4).

Chapter 2: Laws, Regulations, Codes and Standards

We study ongoing facts about legal and regulatory frameworks and codes or standards for wind-resistant design of buildings for 195 countries. This chapter has three sections. Section 2.1 describes the policy for obtaining and understanding relevant information. Section 2.2 summarizes laws, regulations, codes, and standards for each country. Section 2.3 summarizes the findings of this chapter.

Chapter 3: Worldwide Status on Legal and Regulatory Frameworks

We discuss the worldwide status on legal and regulatory frameworks, including provisions related to wind-resistant design of buildings. This chapter has six sections. Section 3.1 reveals the worldwide status in terms of three types of provisions: wind-resistant design liability, wind load calculation methods, and reference wind speeds or pressures. Section 3.2 reveals the worldwide status for each type of provision from the standpoint of jurisdictions. Section 3.3 reveals the worldwide status by dividing the three types of provisions into two requirement groups: wind-resistant design liability, and wind load calculation methods or reference wind speeds or pressures. Section 3.4 discusses the worldwide status from three perspectives: human or economic damage from storms and economic development of countries. Section 3.5 discusses the future worldwide status from national or subnational initiatives. Section 3.6 summarizes the findings of this chapter.

Chapter 4: Worldwide Trends of Codes and Standards

We discuss worldwide trends of codes and standards through classification in principle based on their extent of spread to other regions or countries, or their country of origin. This chapter has five sections. Section 4.1 reviews components modeling atmospheric boundary layers for the categorization of codes and standards. Section 4.2 classifies codes or standards into categories based on atmospheric boundary layer models. Section 4.3 reveals worldwide trends of categorized codes and standards. Section 4.4 discusses future worldwide trends from regional or national initiatives. Section 4.5 summarizes the findings of this chapter.

Chapter 5: Wind Speed Conversions to Various Averaging Times

We explore a unified approach for practically comparing reference wind speeds in national border areas. This chapter has five sections. Section 5.1 reviews an approach applied to averaging time conversions of wind speeds. Section 5.2 examines some components of atmospheric boundary layer models used for averaging time conversions of wind speeds. Section 5.3 computes peak factors for obtaining wind speeds with some averaging times. Section 5.4 discusses practical considerations in comparisons of reference wind speeds in national border areas. Section 5.5 summarizes the findings of this chapter.

Chapter 6: Concluding Remarks

We summarize this thesis from three aspects: quantity (Section 6.1), quality (Section 6.2), and value creation (Section 6.3), based on the findings from Chapters 1 to 5.

(2) Scope of the thesis

Figure 1.8 shows the scope and relations of information covered in Chapters 2 to 5. Chapter 2 covers laws, regulations, codes, and standards and their supplemental information. Of these, Chapter 3 covers laws, regulations, legally binding codes, and legally binding standards, as well as national or subnational initiatives toward establishing them. Chapter 4 covers laws, regulations, codes, and standards, as well as regional or national initiatives toward developing them. Chapter 5 covers laws, regulations, codes, and standards with atmospheric boundary layer models.

Table 1.5 Chapters and sections in this thesis

Chapter	Section
1. Introduction	1.1 Literature Reviews
	1.2 Final Goals, Overall Purpose and Specific objectives
	1.3 Originality and Value
	1.4 Structure and Scope
2. Laws, Regulations, Codes and Standards	2.1 Study Policy
	2.2 Legal and Regulatory Frameworks
	2.3 Conclusions
3. Worldwide Status on Legal and Regulatory Frameworks	3.1 Provisions on Wind-resistant Design of Buildings
	3.2 Legal and Regulatory Jurisdiction
	3.3 Legal and Regulatory Requirements
	3.4 Human or Economic Damage from Storms and Economic Development of Countries
	3.5 National or Subnational Initiatives
	3.6 Conclusions
4. Worldwide Trends of Codes and Standards	4.1 Engineering Models for Categorization
	4.2 Category Classification
	4.3 Worldwide Trends
	4.4 Regional or National Initiatives
	4.5 Conclusions
5. Wind Speed Conversions to Various Averaging Times	5.1 Approach to Averaging Time Conversion of Wind Speeds
	5.2 Atmospheric Boundary Layer Models
	5.3 Peak Factors
	5.4 Practical Considerations
	5.5 Conclusions
6. Concluding Remarks	6.1 Accomplishments in the Thesis
	6.2 Findings from the Thesis
	6.3 Outcomes of the Thesis

Chapter	Scopes
2	Laws, regulations, codes, and standards and their supplemental information
3	Laws regulations, legally binding codes, and legally binding standards, and national or subnational initiatives toward establishing them
4	Laws, regulations, codes, and standards, and regional or national initiatives toward developing them
5	Laws, regulations, codes, and standards with atmospheric boundary layer models

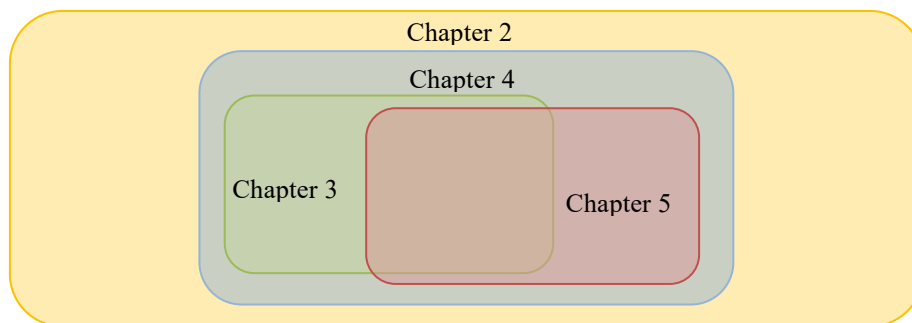


Figure 1.8 Scope and relations of information covered in Chapters 2 to 5

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2 LAWS, REGULATIONS, CODES AND STANDARDS

In this chapter, we study ongoing facts about legal and regulatory frameworks, as well as codes and standards for wind-resistant design of buildings in 195 countries. First, we examine a substantial amount of information related to laws, regulations, codes, and standards, along with their supplemental information. Then, we summarize laws, regulations, codes, and standards for each country. The outcome of this chapter provides the fundamental information for analyses in the subsequent chapters.

We have posted the findings of this chapter on the website of the Wind Engineering Research Center at Tokyo Polytechnic University (TPU) and will regularly update them. The Uniform Resource Locator (URL) of the website is “<https://werc.t-kougei.ac.jp/TPUdatabase.html>”.

Relevant technical notes:

- Hayakawa, A., Matsui, M., and Tamura, Y. 2021. “Legal and Regulatory Frameworks of 195 Countries around the World with Provisions related to Wind-Resistant Design of Buildings, Part 1. Africa, Americas and Asia.” *Wind Engineers, JAWE*, 46(4(169)), 420(78)-439(97).
- Hayakawa, A., Matsui, M., and Tamura, Y. 2021. “Legal and Regulatory Frameworks of 195 Countries around the World with Provisions related to Wind-Resistant Design of Buildings, Part 2. Europe and Oceania.” *Wind Engineers, JAWE*, 46(4(169)), 440(98)-454(112).
- Hayakawa, A., Matsui, M., and Tamura, Y. 2021. “Codes and Standards of 195 Countries around the World for Wind-Resistant Design of Buildings. Part 1. Countries with the Legal and Regulatory Framework.” *Wind Engineers, JAWE*, 46(4(169)), 455(113)-474(132).
- Hayakawa, A., Matsui, M., and Tamura, Y. 2022. “Codes and Standards of 195 Countries around the World for Wind-Resistant Design of Buildings. Part 2. Countries without a Legal and Regulatory Framework.” *Wind Engineers, JAWE*, 47(2(171)), 83(83)-95(95).

2.1 Study Policy

2.1.1 Target countries and jurisdictions

(1) Target countries

A total of 195 countries, 193 of which are member states of the United Nations (UN) and two of which are observer states at the UN General Assembly, were targeted in this thesis. Figure 2.1 shows the official UN world map (UN 2020). Among inhabited territories, Western Sahara, where sovereignty has not yet been determined, was untargeted in this thesis.

(2) Target jurisdictions

Two levels of legal and regulatory jurisdiction, from the country (first) level to the state or province (second) level, were covered in this thesis. Overseas territories were allocated to the second level. However, if no law or regulations were identified even at the first or second levels, the city (third) level was also covered, but only if the city was a political or economic center. Table 2.1 shows representative legislative bodies for each level of government.

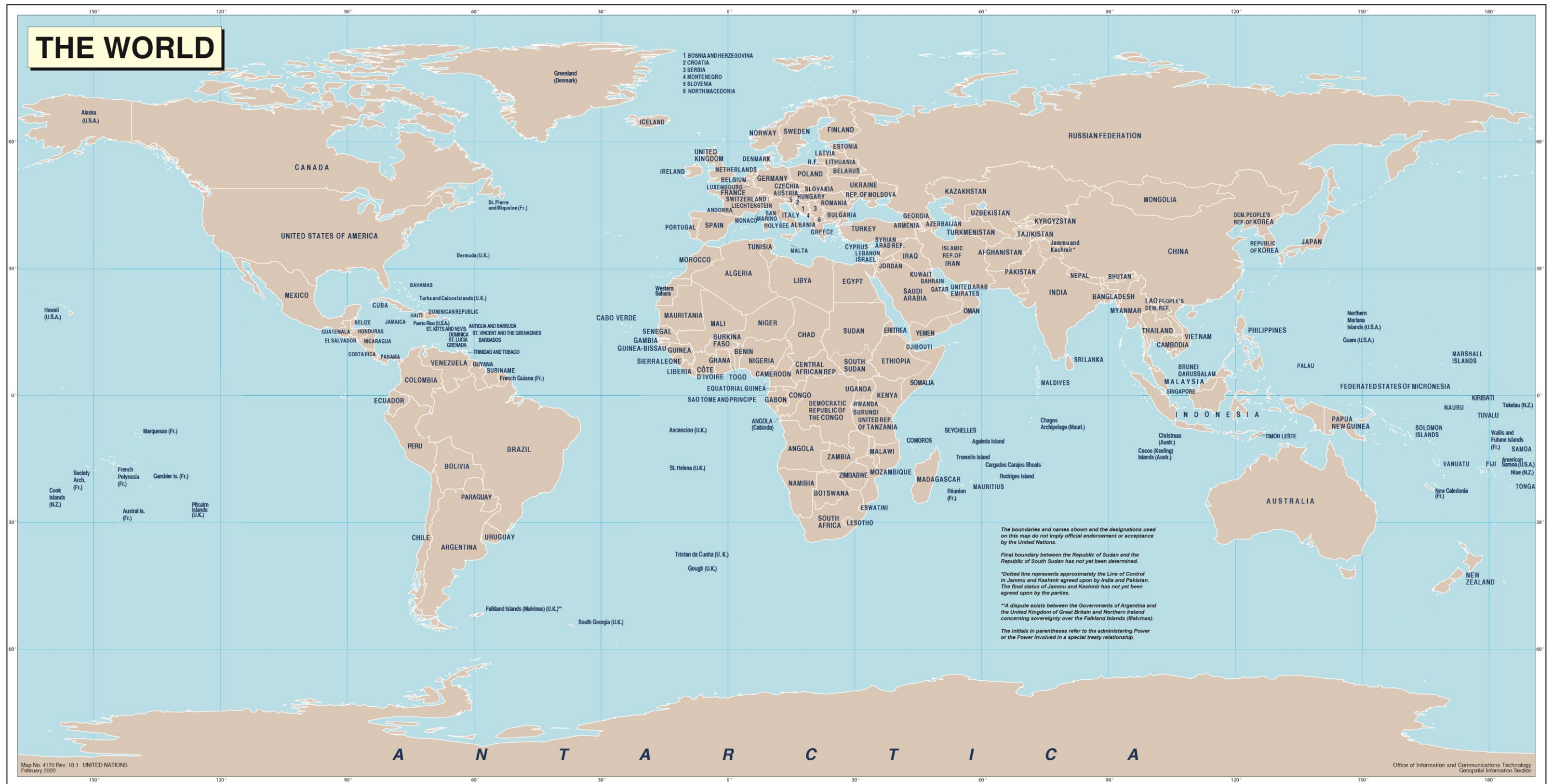


Figure 2.1 Official UN world map

Table 2.1 Legislative bodies for each level of government

Level of government		Legislative body
First	National government	Diet, Parliament, Congress, Assembly, Council
		Government, Cabinet, President
		Ministry, Department, Secretary, Agency, Institution
Second	State, Provincial, Municipal, Prefectural government	Assembly, Council
Third	City government	Assembly, Council

2.1.2 Sources and considerations

(1) Sources for the study

Online libraries of laws and regulations, official gazettes, and study reports powered by national or international agencies were the main study sources. Codes, standards, guidelines, and manuals developed by authorities, governmental agencies, or academic or professional bodies were also covered as the study sources. Documents on administrative guidance and from technical consultations with authorities, project-related specification documents of public works, academic writings of every kind, and internet articles including Facebook posts were referenced as well. These study sources related to wind-resistant design of buildings were collected by making full use of Google Search and Translate. Table 2.2 shows the main commands and keywords in the case of English. These keywords were effectively used in combination together with Google Site Search (“site:” command). Besides, necessary study sources were purchased online if possible. If that was impossible, questionnaires or interviews by email with related parties including local consultants, researchers and officials were attempted based on information obtained on the web.

(2) Considerations in the study

It was expected at the start of this study that it would take some time not only to obtain relevant information for all countries but also to decipher non-English documents. Therefore, the following matters were considered in three phases: 1) to obtain relevant information from other countries, 2) to correctly read the contents of the information, and 3) to accurately understand them:

1) Phase to obtain relevant information from other countries

It was harder to obtain relevant information from other countries, especially those in Africa, while staying in Japan, than expected. As a matter of fact, for hard-to-find information, more than 100 email interviews were attempted with consultants, researchers, or officials from various countries. Of these, we succeeded in conducting email interviews with about 30 individuals and multiple email interviews with only 10 individuals. Of particular concern was fewer responses from researchers than those from consultants or officials. However, no intention of clear refusal was received from them. Therefore, it was important to challenge them without giving up, as well as to prepare multiple contact individuals. These matters were considered in the phase to obtain relevant information from other countries.

2) Phase to correctly read contents of relevant information

Language issues should not be ignored. Some documents could not be copied and pasted or applied to optical character recognition (OCR). Therefore, we needed to transcribe such documents into Google Translate to correctly read them. However, it was time-consuming to accurately digitize documents written in non-Latin script languages. In addition, some documents were published only in minority languages. Google Translate did not support some minor languages such as Faroese. Therefore, we needed to search for supplemental documents written in major languages. Otherwise, we had to outsource them to accurately translate minority languages into English. These matters were considered in the phase to correctly read

contents of relevant documents.

3) Phase to accurately understand contents of relevant information

The meaning of legal and regulatory terminologies such as law, act, code, regulation, order, ordinance, decree, decision, bylaws, rule, deliberation, resolution, notification, notice, and so on, differed from country to country. Instead of focusing on the meaning of these terminologies, therefore, finding out who developed or enacted legislation led to correctly understanding the positioning thereof in each country. Table 2.1 is helpful in this regard. In addition, reports of international or national organizations, as well as research articles were proactively referenced if the necessary information was not firsthand. Some reports or articles mentioned that a specific country had a building code while others denied that. In many cases, both mentions were both correct and incorrect. Rather than focusing on just a word such as building code, therefore, understanding differences among scopes (e.g., design, structure, environment) targeted in reports or articles led to correctly judging the presence or absence of a legal and regulatory framework for a specific field. Furthermore, although codes or standards developed in each country had nothing to do with those of other countries at first glance, many of them had been developed with various adjustments based on local conditions to those of other countries. Before figuring out their technical details, finding out when, where, by whom, and how laws, regulations, codes, or standards were developed led to accurately deciphering them. These matters were considered in the phase to accurately understand contents of relevant information.

(3) Accessibility to study sources

Some kinds of relevant information related to wind-resistant design of buildings were obtained through study sources for all 195 countries as shown in Table 2.3.

Table 2.2 Main commands and keywords for Google Search (in the case of English)

Google Search command		- site: URL, e.g., a country code top-level domain (in case of Japan:.jp) or a subdomain (if it can be identified): central or local government, parliament or congress, ministry, national agency, national press, international organization, university, institution, academic or professional society, etc.
Keyword related to:	Institution	- name of region, country, state, province, city, town, etc. - name of central or local governments, parliament or congress, ministry, national agency, national press, international organization, university, institution, academic or professional society, etc.
	Legislation	- name of law, code, regulations, decree, resolution, report, etc. - general term: “legislation”, “building code”, “building standard”, “building regulations”, “building act”, “building control”, “physical planning”, “public health”, “construction law”, “construction act”, “building permit”, “construction permit”, etc.
	Technology	- name of standard, code of practice, manual, technical specifications, report, tender document, program, project of public works, etc. - general term: “wind load”, “wind design”, “wind code”, “wind speed”, “wind velocity”, “basic wind speed”, “reference wind speed”, “wind map”, “wind chart”, “structural design”, “structural engineering”, etc.

Table 2.3 Accessibility to study sources

Region	Subregion	Number of target countries	Number of accessible countries	Number of inaccessible countries	Accessibility rate (%)
Africa	Eastern Africa	18	18	0	100.0
	Middle Africa	9	9	0	100.0
	Northern Africa	6	6	0	100.0
	Southern Africa	5	5	0	100.0
	Western Africa	16	16	0	100.0
	Subtotal	54	54	0	100.0
Americas	Caribbean	13	13	0	100.0
	Central America	8	8	0	100.0
	Northern America	2	2	0	100.0
	South America	12	12	0	100.0
	Subtotal	35	35	0	100.0
Asia	Central Asia	5	5	0	100.0
	Eastern Asia	5	5	0	100.0
	South-eastern Asia	11	11	0	100.0
	Southern Asia	9	9	0	100.0
	Western Asia	18	18	0	100.0
	Subtotal	48	48	0	100.0
Europe	Eastern Europe	10	10	0	100.0
	Northern Europe	10	10	0	100.0
	Southern Europe	15	15	0	100.0
	Western Europe	9	9	0	100.0
	Subtotal	44	44	0	100.0
Oceania	Australia and New Zealand	2	2	0	100.0
	Melanesia	4	4	0	100.0
	Micronesia	5	5	0	100.0
	Polynesia	3	3	0	100.0
	Subtotal	14	14	0	100.0
Total		195	195	0	100.0

2.2 Legal and Regulatory Frameworks

Legal and regulatory frameworks including provisions regarding wind-resistant design of buildings were identified in 137 of 195 countries, accounting for 70% of the total. Table 2.4 shows the 137 countries by check marks: “✓” and Figure 2.2 represents them by colored blue on a world map. At the same time, legal and regulatory frameworks including provisions regarding wind-resistant design of buildings were not identified in the remaining 58 countries, accounting for 30% of the total. Table 2.4 also shows the 58 countries by hyphens: “-” and Figure 2.2 also represents them by colored gray on the world map. The numerical value in parentheses in Table 2.4: () shows the number of countries that lie within each region and subregion. Figure 2.2 individually shows the status of 30 small countries with less than 5,000 km². Table 2.5 shows the breakdowns for each subregion. The divisions of region and subregion follow in principle the United Nations geoscheme (UNSD 1999). The tables and figure reveal that 137 countries are widely distributed in the Americas, Asia, Europe, and Oceania, and meanwhile the 58 countries are concentrated in Africa, especially Middle Africa and Western Africa.

(1) Countries whose legal and regulatory frameworks were identified

The legal and regulatory frameworks for 137 countries are summarized into five regions: 2.2.1 Africa, 2.2.2 Americas, 2.2.3 Asia, 2.2.4 Europe, and 2.2.5 Oceania. The numbers of countries are 24, 28, 37, 40, and 8, respectively. Furthermore, each region is organized into subregions. For Africa, Subsection 2.2.1 is divided into five subregions: (1) Eastern Africa, (2) Central Africa, (3) Northern Africa, (4) Southern Africa, and (5) West Africa. The numbers of countries are 9, 1, 3, 5, and 6, respectively. For the Americas, Subsection 2.2.2 is divided into four subregions: (1) Caribbean, (2) Central America, (3) Northern America, and (4) South America. The numbers of countries are 8, 8, 2, and 10, respectively. For Asia, Subsection 2.2.3 is divided into five subregions: (1) Central Asia, (2) Eastern Asia, (3) South-eastern Asia, (4) Southern Asia, and (5) Western Asia. The numbers of countries are 5, 4, 7, 7, and 14, respectively. For Europe, Subsection 2.2.4 is divided into four subregions: (1) Eastern Europe, (2) Northern Europe, (3) Southern Europe, and (4) Western Europe. The numbers of countries are 10, 9, 13, and 8, respectively. For Oceania, Subsection 2.2.5 is divided into four subregions: (1) Australia and New Zealand, (2) Melanesia, (3) Micronesia, and (4) Polynesia. The numbers of countries are 2, 3, 1, and 2, respectively.

(2) Countries whose legal and regulatory frameworks were not identified

De facto industry codes or standards related to wind-resistant design of buildings, as well as current situations or ongoing efforts toward the establishment of laws or regulations, are also summarized for 58 countries. The numbers of countries are 30, 7, 11, 4, and 6 in Africa, the Americas, Asia, Europe, and Oceania, respectively. Also, the numbers of countries in each subregion are as follows. For Africa, the numbers of countries are 9, 8, 3, 0, and 10 in Eastern Africa, Central Africa, Northern Africa, Southern Africa, and West Africa, respectively. For the Americas, the numbers of countries are 5, 0, 0, and 2 in the Caribbean, Central America, Northern America, and South America, respectively. For Asia, the numbers of countries are 0, 1, 4, 2, and 4 in Central Asia, Eastern Asia, South-eastern Asia, Southern Asia, and

Western Asia, respectively. For Europe, the numbers of countries are 0, 1, 2, and 1 in Eastern Europe, Northern Europe, Southern Europe, and Western Europe, respectively. For Oceania, the numbers of countries are 0, 1, 4, and 1 in Australia and New Zealand, Melanesia, Micronesia, and Polynesia, respectively.

(3) Study results and overview

The relationships among laws, regulations, codes, and standards, as well as their jurisdictional and technical scopes, are presented in an overview for each country. However, if laws or regulations are identified in a superordinate legislative jurisdiction, they are not described in the subordinate legislative jurisdictions. Also, if they are not identified in the superordinate legislative jurisdiction but are identified in the subordinate legislative jurisdictions, they are described for only the main states or provinces, overseas territories, or political or economic center cities. Additionally, codes or standards that fall outside legal and regulatory frameworks are also given an overview from the following viewpoints:

- codes or standards referenced for development,
- supplemental information for codes or standards,
- undefined or defect information on codes or standards (e.g., reference wind speeds), or
- de facto industry standards.

It should be noted that information before 2010, when this study was initiated, is also considered if information for understanding the status of laws, regulations, codes, and standards is deficient. The laws, regulations, codes, and standards referred to in this chapter are listed in Appendix 2.

(4) Simplified document code

The document code here is unique for this thesis and not always the same as the official document code. For example, because the European Union (EU) standard (CEN 2005): Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions was published after it was translated into each mother tongue and newly numbered as a national standard of each country with its content and style unchanged, the newly numbered standards by country were represented by EN'05 to simplify the notation in sentences, as well as the citation of references in this thesis.

Table 2.4 List of the establishment status of legal and regulatory frameworks in 195 countries

Africa (54)		Burkina Faso	-	Bolivia	✓	Sri Lanka	-	Andorra	-
Eastern Africa (18)		Cabo Verde	✓	Brazil	✓	Western Asia (18)		Bosnia and Herzegovina	✓
Burundi	-	Ivory Coast	✓	Chile	✓	Armenia	✓	Croatia	✓
Comoros	-	Gambia	-	Colombia	✓	Azerbaijan	✓	Greece	✓
Djibouti	-	Ghana	✓	Ecuador	✓	Bahrain	-	Holy See	✓
Eritrea	-	Guinea-Bissau	-	Guyana	-	Cyprus	✓	Italy	✓
Ethiopia	✓	Guinea-Conakry	-	Paraguay	✓	Georgia	✓	Malta	-
Kenya	-	Liberia	-	Peru	✓	Iraq	✓	Montenegro	✓
Madagascar	✓	Mali	-	Suriname	✓	Israel	✓	North Macedonia	✓
Malawi	✓	Mauritania	✓	Uruguay	-	Jordan	✓	Portugal	✓
Mauritius	-	Niger	-	Venezuela	✓	Kuwait	-	San Marino	✓
Mozambique	✓	Nigeria	✓	Asia (48)		Lebanon	✓	Serbia	✓
Rwanda	✓	Senegal	✓	Central Asia (5)		Oman	-	Slovenia	✓
Seychelles	✓	Sierra Leone	-	Kazakhstan	✓	Palestine	✓	Spain	✓
Somalia	-	Togo	-	Kyrgyzstan	✓	Qatar	✓	Western Europe (9)	
South Sudan	-	Americas (35)		Tajikistan	✓	Saudi Arabia	✓	Austria	✓
Tanzania	✓	Caribbean (13)		Turkmenistan	✓	Syria	✓	Belgium	-
Uganda	✓	Antigua and Barbuda	✓	Uzbekistan	✓	Turkey	✓	France	✓
Zambia	-	Bahamas	✓	Eastern Asia (5)		United Arab Emirates	✓	Germany	✓
Zimbabwe	✓	Barbados	-	China	✓	Yemen	-	Liechtenstein	✓
Middle Africa (9)		Cuba	✓	Japan	✓	Europe (44)		Luxembourg	✓
Angola	✓	Dominica	✓	Mongolia	✓	Eastern Europe (10)		Monaco	✓
Cameroon	-	Dominican Republic	-	North Korea	-	Belarus	✓	Netherlands	✓
Central African Republic	-	Grenada	✓	South Korea	✓	Bulgaria	✓	Switzerland	✓
Chad	-	Haiti	-	South-eastern Asia (11)		Czech	✓	Oceania (14)	
Congo-Brazzaville	-	Jamaica	✓	Brunei	✓	Hungary	✓	Australia and New Zealand (2)	
Congo-Kinshasa	-	St. Kitts and Nevis	✓	Cambodia	-	Moldova	✓	Australia	✓
Equatorial Guinea	-	St. Lucia	-	Indonesia	✓	Poland	✓	New Zealand	✓
Gabon	-	St. Vincent and the	✓	Laos	-	Romania	✓	Melanesia (4)	
Sao Tome and Principe	-	Grenadines	-	Malaysia	✓	Russia	✓	Fiji	✓
Northern Africa (6)		Trinidad and Tobago	-	Myanmar	-	Slovakia	✓	Papua New Guinea	✓
Algeria	✓	Central America (8)		Philippines	✓	Ukraine	✓	Solomon Islands	-
Egypt	✓	Belize	✓	Singapore	✓	Northern Europe (10)		Vanuatu	✓
Libya	-	Costa Rica	✓	Thailand	✓	Denmark	✓	Micronesia (5)	
Morocco	✓	El Salvador	✓	Timor-Leste	-	Estonia	-	Federated States of	-
Sudan	-	Guatemala	✓	Vietnam	✓	Finland	✓	Micronesia	✓
Tunisia	-	Honduras	✓	Southern Asia (9)		Iceland	✓	Kiribati	✓
Southern Africa (5)		Mexico	✓	Afghanistan	-	Ireland	✓	Marshall Islands	-
Botswana	✓	Nicaragua	✓	Bangladesh	✓	Latvia	✓	Nauru	-
Eswatini	✓	Panama	✓	Bhutan	✓	Lithuania	✓	Palau	-
Lesotho	✓	Northern America (2)		India	✓	Norway	✓	Polynesia (3)	
Namibia	✓	Canada	✓	Iran	✓	Sweden	✓	Samoa	✓
South Africa	✓	United States	✓	Maldives	✓	United Kingdom	✓	Tonga	✓
Western Africa (16)		South America (12)		Nepal	✓	Southern Europe (15)		Tuvalu	✓
Benin	-	Argentina	✓	Pakistan	✓	Albania	✓		

Notes: check marks: "✓" show 137 countries whose legal and regulatory frameworks were identified; hyphens: "-" show 58 countries whose legal and regulatory frameworks were not identified; the numerical value in parentheses: () shows the number of countries that lie within each region and subregion.

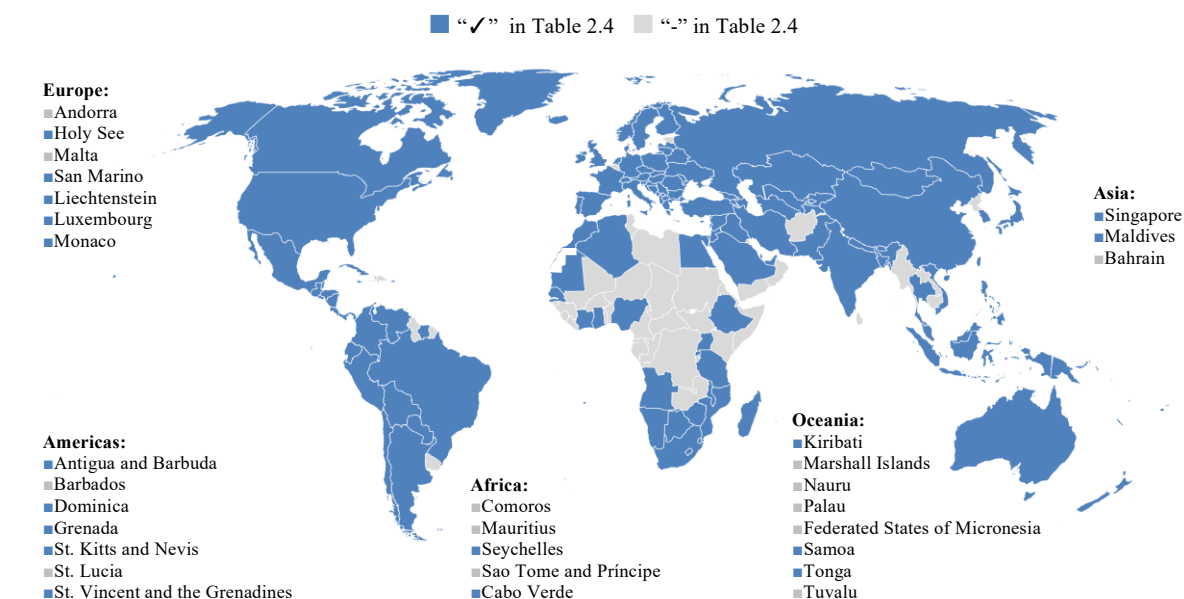


Figure 2.2 Distribution of the establishment status of legal and regulatory frameworks in 195 countries

Table 2.5 Breakdown of 195 countries on the establishment of legal and regulatory frameworks

Region	Subregion	Number of target countries		Number of countries with a legal and regulatory framework		Number of countries without any legal and regulatory framework	
Africa	Eastern Africa	18	54	9	24	9	30
	Middle Africa	9		1		8	
	Northern Africa	6		3		3	
	Southern Africa	5		5		0	
	Western Africa	16		6		10	
Americas	Caribbean	13	35	8	28	5	7
	Central America	8		8		0	
	Northern America	2		2		0	
	South America	12		10		2	
Asia	Central Asia	5	48	5	37	0	11
	Eastern Asia	5		4		1	
	South-eastern Asia	11		7		4	
	Southern Asia	9		7		2	
	Western Asia	18		14		4	
Europe	Eastern Europe	10	44	10	40	0	4
	Northern Europe	10		9		1	
	Southern Europe	15		13		2	
	Western Europe	9		8		1	
Oceania	Australia and New Zealand	2	14	2	8	0	6
	Melanesia	4		3		1	
	Micronesia	5		1		4	
	Polynesia	3		2		1	
Total		195		137		58	

2.2.1 Africa

(1) Eastern Africa

1) Burundi

No regulations on structural safety requirements for buildings are enforced under the *Code of Town Planning, Housing and Construction* (2016). Additionally, no information about codes or standards was available for this study, except for the outdated information that the French (FR) technical documents: NV 65s had once been consulted in practice. (MEFCD 2009)

2) Comoros

No regulations on structural safety requirements for buildings are enforced under the *Code of Town Planning and Housing* (1986). Additionally, no information about codes or standards was available for this study, except for the outdated information that NV 65s had once been consulted in practice. (JICA 1984a)

3) Djibouti

The governmental order (GDJ 2015), which defines the procedure for obtaining building permits, does not specify any structural safety requirements for buildings. Additionally, no information about codes or standards was available for this study, except for the outdated information that NV 65s had once been consulted in practice. (JICA 1993)

4) Eritrea

The Interim Building Regulations for the capital, Asmara, were not accessible for this study. Additionally, no information about codes or standards was available for this study, except for the outdated information that United Kingdom (UK) national standards or United States (US) model codes had once been applied to design reviews, and Ethiopian national standards had once been accepted in practice. (JICA 2003)

5) Ethiopia

The national standard (ESA 2015): CES 145'15, whose source is the European Union (EU) standard (CEN 2005): EN'05, is authorized as mandatory in accordance with the Standards Agency Establishment Council of Ministers Regulation (CMET 2010).

6) Kenya

Finalization of the National Building Code (MTIHUPW 2020), which requires compliance with EN'05 with the UK national annex (BSI 2010): BS EN NA'10, is in progress under the *National Construction Authority Act, 2011* (2011). (CSTIHUP 2022) EN'05 with BS EN NA'10 and statistically analyzed wind speeds (Munyua 2020) may be consulted in practice.

7) Madagascar

The Rules for Wind Resistant Constructions (CPGU 2018): RFCC'18, which require compliance with the FR technical document (CSTB 2000): NV 65'00, are enforced in accordance with the Wind Resistant Building Construction Regulations (GMG 2010).

8) Malawi

The Building Bylaws, which require buildings to withstand wind loads, are enforced in the center of commerce, Blantyre, under the *Local Government Act, 1998* (1998). (WB 2019) However, the national standard (MBS 2010): MS 820'10, whose source is the South African (ZA) national standard (SABS 1994): SABS 0160'89, is not mandatory in the Bylaws.

9) Mauritius

No regulations on structural safety requirements for buildings are enforced under the *Building Control Act* (2012). The UK national standard (BSI 1972): BS CP3 CV2'72 and a reference wind speed recommended by authorities have been consulted in practice. (JICA 2012)

10) Mozambique

The General Regulation of Urban Buildings (DSOPT 1960) requires consideration of wind actions on metal structures. In addition, the Portuguese (PT) ministerial ordinance (MU 1962), which was enacted to extend the PT ministerial regulation (MOP 1961): RSEP'61 to overseas territories at the time of the PT overseas territory, is still inherited. (Dgedge 2015) The PT ministerial regulation (MHOPT 1983): RSA'83 may also be consulted in practice. (FFH 2019)

11) Rwanda

The Urban Planning and Building Regulations (MINIFRA 2019a), which provide the Building Code (MINIFRA 2019b), are enforced under the *Urban Planning and Building Law* (2012). Compliance with the Code is established through the national standard (RSB 2011): RS 144-2'11, which was developed using examples from EN'05.

12) Seychelles

The Town and Country Planning Regulations (GSC 1975): TCPR'75, which require compliance with BS CP3 CV2'72, are enforced under the *Town and Country Planning Act* (1972).

13) Somalia

The establishment of the urban policy regulatory framework, including a building development code (MPWRH 2017a), is underway. (MPWRH 2017b) For the capital, Mogadishu, the US model code (ICC 2012): IBC'12, which requires the US academic society standard (ASCE 2010): ASCE 7'10, may be accepted in accordance with the Building Standards Policy (MPWR 2019). For Somaliland, one's own efforts have also been made to introduce a building code. (Fashina et al. 2020)

14) South Sudan

The Building Regulations for Central Equatoria State were not accessible for this study. Most standards for industrial products have followed UK national standards. (JICA 2011) Statistically analyzed wind speeds (Wahab et al. 2001) may be consulted in practice.

15) Tanzania

The Urban Planning Regulations (MLHSD 2018) are enforced under the *Urban Planning Act, 2007* (2007). Compliance with the Regulations is established through the Technical Guideline (MLHSD 2015): BRU-TG2'15, which accepts BS CP3 CV2'72.

16) Uganda

The Building Control Regulations (MWT 2012), which require compliance with the Structural Design Guidelines (MWHC 2005): SDGUG'05, are enforced under the *Building Control Act* (2013).

17) Zambia

The Public Health (Building) Regulations (GZM 1965) do not require buildings to withstand winds. No information about codes or standards was available for this study, except for the outdated information that BS CP3 CV2'72 and statistically analyzed wind speeds had been consulted in practice. (JICA 1984b)

18) Zimbabwe

The Building By-laws (MLGUD 1979) are enforced in the capital, Harare, under the *Urban Councils Act [Chapter 29:15]* (1995). The By-laws adopt the Model Building By-laws (MLH 1978), which require compliance with the Central African standard (CASI 1977): CAS 160.2'77. The source of CAS 160.2'77 is BS CP3 CV2'72.

(2) Middle Africa

1) Angola

The General Regulation of Urban Buildings (MUHAO 2007), which requires building walls to withstand winds, is enforced under the *Land and Urban Planning Law* (2004). However, the Regulation does not define any specific wind-resistant requirements, so the ZA national standard (SABS 2010): SANS 10160-3'10, which is supplemented by EN'05, may be consulted in practice. (Wentzel 2018) For the capital, Luanda, EN'05 applies to design reviews. (LPGUL 2020)

2) Cameroon

The Rules of Land Use and Construction (GCM 2016) do not define any structural safety requirements for buildings. NV 65'00 and the de facto reference wind speeds have been consulted in practice. (François 2017)

3) Central African Republic

Neither information on building regulations nor efforts toward their establishment were accessible for this study. Additionally, no information about codes or standards was available for this study, except for the outdated information that NV 65s and the wind speed threshold regarded as force majeure had once been consulted in practice. (JICA 1987)

4) Chad

No regulations on structural safety requirements for buildings were identified under the *Construction Law* (2010). NV 65s and statistically analyzed wind speeds (Bechir 2016; Syro 2016) may be consulted in practice.

5) Congo-Brazzaville

No regulations on structural safety requirements for buildings are enforced under the *Code of Town Planning and Construction* (2019). NV 65s have been consulted in practice. (OMS 2015)

6) Congo-Kinshasa

The Decree on Town Planning (MCBE 1957), which is supposed to be superseded by the Code of Town Planning and Construction, does not define any structural safety requirements for buildings. NV 65s and the de facto reference velocity pressures have been consulted in practice. (Nzundu 2016)

7) Equatorial Guinea

Neither information on building regulations nor efforts toward their establishment were accessible for this study. The Spanish basic document (MV 2009): CTE DB-SE-AE'09, which was developed using examples from EN'05, has been consulted in practice. (Akumu 2016)

8) Gabon

The General Rules on Town Planning (MHUEDD 2012) do not define any structural safety requirements for buildings. NV 65s have been consulted in practice. (Viglo 2013)

9) Sao Tome and Principe

The current General Regulation of Construction and Urban Housing was not accessible for this study. The draft General Regulation of Urban Building (MIRNA 2020), which is supposed to eventually supersede the current regulation pursuant to the National Spatial Planning Plan (CEP-PNOT 2022), does not require buildings to withstand winds. However, EN'05 with the PT national annex (IPQ 2010): NP EN NA'10 is recognized as one of the current standards in the country. (UNDP 2022)

(3) Northern Africa

1) Algeria

The Snow and Wind Regulations (MHUV 2013): DTR RNV'13, whose source is EN'05, are enforced in accordance with the governmental decree (GDZ 2008), which establishes the powers of the

responsible minister.

2) Egypt

The Code of Practice for Calculating Loads and Forces (MHUUC 2012): ECP-201'12, some definitions of which were based on EN'05, is enforced under the *Law on Basis of Design and Conditions* (1964).

3) Libya

Neither information on building regulations nor efforts toward their establishment were accessible for this study. US model codes: IBCs or US academic society standards: ASCE 7s have been consulted in practice. (CEH 2014; Thabet et al. 2015) Statistically analyzed wind speeds (Abohedma and Alshebani 2010) may be consulted in practice.

4) Morocco

The Aseismic Construction Regulations (MHPV 2011), which require consideration of the most unfavorable conditions including wind effects, are enforced under the *Law on Town Planning* (1992). However, the Regulations do not define any specific wind-resistant requirements, so the FR ministerial rules (MRU 1947): NV 46'47, or the FR technical document (CSTB 1987): NV 65'87, as well as the common specifications (MTP 1990), may be consulted in practice. (MTP 1987; MUHMA 1956) No authorized reference velocity pressures for NV 46'47 were identified in this study. The draft Construction Code (MHPV 2015), which is supposed to require compliance with EN'05 with the draft national annex (IMANOR 2020): PMN EN NA'20, has not yet been finalized. The source of PMN EN NA'20 is the FR national annex (AFNOR 2008): NF EN NA'08.

5) Sudan

The Building Regulations for Khartoum State were not accessible for this study. UK national standards have been consulted in practice. (JICA 2015) Statistically analyzed wind speeds (Wahab et al. 2001) may be consulted in practice.

6) Tunisia

No regulations on structural safety requirements for buildings are enforced under the *Code of Land Use Planning, Town Planning and Construction* (2015). The national standard (INNORPI 2004): NT 30.185'04, whose source is the EU standard (CEN 1995): ENV'95, may be consulted in practice. However, NV 65s and the de facto reference velocity pressures have been accepted in practice. (Ayadi and Abdelkefi 2015)

(4) Southern Africa

1) Botswana

The Building Control Regulations (GBW 1981), which accept BS CP3 CV2'72 and the ZA Standard Building Regulations (DICT 1970): SBR'70, are enforced under the *Building Control Act* (1981). The

national standard (BOBS 2014): BOS 536-3'14, whose source is the ZA national standard (SABS 2011): SANS 10160-3'11, is not mandatory. BOS 536-3'14 is supplemented by EN'05.

2) Eswatini

The Standard Building Regulations (GSZ 1969), which require compliance with the ZA Standard Building Regulations (SABS 1966): SBR'66, are enforced under the *Building Act, 1968* (1968). Their revised editions (SCG 2018a; b), which adopt the ZA national standard (SABS 2018): SANS 10160-3'18, have not yet superseded the Act and the Regulations. SANS 10160-3'18 is supplemented by EN'05.

3) Lesotho

The Building Control Regulations (MLGLS 1999), which require buildings to withstand winds, are enforced under the *Building Control Act 1995* (1995). However, the Regulations do not define any specific wind-resistant requirements, so ZA national standards: SABS 0160/SANS 10160-3, some of which are supplemented by EN'05, may be consulted in practice. (LSP Construction 2018)

4) Namibia

The Building Regulations are enforced in at least two municipalities under the *Local Authorities Act, 1992* (1992). Of these, the Building Regulations (MCWH 1969), which require consideration of wind forces, are enforced in the capital, Windhoek, but do not define any specific wind-resistant requirements. Therefore, SANS 10160-3'18, which is recognized as one of the national standards, may be consulted in practice. (Heydenrych 2018) On the other hand, the Building Regulations (MCWB 1995), which adopt SBR'70, are enforced in the largest commercial port, Walvis Bay, in accordance with Section 14bis of the *Standards Act, 1962* (1964).

5) South Africa

The National Building Regulations (SABS 1990), which require compliance with the national standard (SABS 2018): SANS 10160-3'18, are enforced under the *National Building Regulations and Building Standards Act, 1977* (1977).

(5) Western Africa

1) Benin

The Regulation of the Issuance of Building Permit (GBJ 2014) does not define any structural safety requirements for buildings. NV 65s and statistically analyzed wind speeds (Gbaguidi et al. 2011) may be consulted in practice.

2) Burkina Faso

No regulations on structural safety requirements for buildings are enforced under the *Code of Town Planning and Construction* (2006). NV 65s have been consulted in practice. (JICA 2014)

3) Cabo Verde

The Technical Building Code (MIEM/MAOT 2012), which requires building walls to withstand winds, is enforced under the General Regulation of Construction and Urban Housing (CMCV 2011). The Code does not define any specific wind-resistant requirements but places top priority on compliance with PT regulations: RSA'83 and EN'05 with NP EN NA'10. Of these, EN'05 with NP EN NA'10 has been recommended in practice. (Martins 2018)

4) Ivory Coast

The *Code of Construction and Housing* (2019) requires constructions to withstand strong winds. However, no relevant regulation is enforced under the Code. No information about codes or standards was available for this study, except for the outdated information that NV 65s had once been consulted in practice. (JICA 2003)

5) Gambia

The Development Control Regulations, which are enforced under the *Physical Planning and Development Control Act, 1990* (1991), were not accessible for this study. All technical or quality measures for buildings apparently follow UK or EU standards. (JICA 2008a)

6) Ghana

The National Building Regulations (MWHGH 1996): NBRGH'96, which require compliance with the UK national standard (BSI 1970): BS CP3 CV2'70, are enforced under the *Local Governance Act, 2016* (2016). Furthermore, the Building Code (GSA 2018): GS 1207'18, whose source is BS CP3 CV2'70, is also accepted under the *Land Use and Spatial Planning Act, 2016* (2016).

7) Guinea-Bissau

The General Regulation of Construction and Urban Housing was not accessible for this study. EN'05 has been consulted in practice. (JICA 2011)

8) Guinea-Conakry

No regulations on structural safety requirements for buildings are enforced under the *Code of Construction and Housing* (2015). No information about codes or standards was available for this study, except for the outdated information that NV 65s had once been consulted in practice. (JICA 2006)

9) Liberia

The outdated Building Code was not accessible for this study. IBCs, which require any edition of ASCE 7s, have been consulted in practice. (UN-Habitat 2014)

10) Mali

The Law establishing the General Construction Rules and its reinforcing decree were not accessible

for this study. No information about codes or standards was available for this study, except for the outdated information that NV 65s had once been consulted in practice. (JICA 2009)

11) Mauritania

The General Construction Regulations (MEUHAR 2007), which require constructions to withstand extreme climatic loads, are enforced in accordance with the ministerial decree (MHUAT 2020), which establishes the powers of the responsible minister. However, the Regulations do not define any specific wind-resistant requirements. NV 65s may be consulted in practice. (MHUAT 2015)

12) Niger

The Law on Fundamental Principles of Construction and Housing and its application decree were not accessible for this study. No information about codes or standards was available for this study, except for the outdated information that NV 65s had once been consulted in practice. (JICA 1988)

13) Nigeria

The Building Control Regulation (MPPUD 2019), which requires compliance with the National Building Code (FMLHUD 2006): NBCNG'06, is enforced in metropolitan Lagos under the Urban and Regional Planning and Development Law (LSHA 2010). NBCNG'06 is supplemented by UK national standards. However, NBCNG'06, which does not define locations or regions for each reference wind speed, remains so incomplete that it needs rectification. (Sanni 2016) The national standard (SON 1973): NCP 001-3'73 is not mandatory.

14) Senegal

The Construction Code (Regulatory part) (GSN 2010), which requires constructions to withstand extreme climatic loads, is enforced under the *Construction Code (Legislative part)* (2009). However, the national standard (ASN 2008): NS 02-058'08, whose source is NV 65s, is not included in the Codes.

15) Sierra Leone

Even for the capital, Freetown, the Improvement Rules (GCSL 1955) do not require buildings to withstand winds. UK national standards or EU standards have been consulted in practice. (JICA 2010) Most of the outdated policies or acts including the Rules have been reviewed through the draft Building Control Act and Regulations (MWHI 2014), which seek to meet the US model code (ICC 2015): IBC'15. (MLHE 2019) IBC'15 requires ASCE 7'10.

16) Togo

The Decree on Urban Planning and Building Permits (GTG 1967) does not define any structural safety requirements for buildings. NV 65s and statistically analyzed wind speeds (Amey 2005) may be consulted in practice.

2.2.2 Americas

(1) Caribbean

1) Antigua and Barbuda

The Land Development and Control Regulations (MWHAG 1996) are enforced under the *Physical Planning Act, 2003* (2003). Compliance with the Regulations is established through the Building Code (DCA 1995), which accepts the Caribbean Building Code (CARICOM 1985): CUBiC'85. The Organization of Eastern Caribbean States (OECS) Building Code (OECS 2016): OECS-BC'16, which accepts CUBiC'85, the draft Bajan (BD) national standard (BNSI 2010): BNS DPC'10, and the US academic society standards (ASCE 2005; 2010): ASCE 7'05 and ASCE 7'10, is not mandatory. CUBiC'85 was developed using examples from the draft edition of the International Organization for Standardization (ISO) standard (ISO 1997): ISO 4354'97. BNS DPC'10 is exactly the same as the BD professional society standard (BAPE 1981): BNS CP 28'81, which was developed using examples from BS CP3 CV2'72 and the draft edition of the US national standard (ANSI 1982): ANSI A58.1'82.

2) Bahamas

The Building Code (MWU 2003): BCBS'03, which requires compliance with the US academic society standard (ASCE 1990): ASCE 7'88, is enforced under the *Buildings Regulation Act* (1971). The use of a more current US academic society standard is also acceptable in practice. (wallerd (Structural) 2013)

3) Barbados

The national standard (BNSI 2013a): BNS TR 28'13, which is exactly the same as BNS DPC'10, may be consulted in practice. The *Building Standards Act Bill* (2018), which requires the National Building Code (BNSI 2013b) and BNS TR 28'13, is under deliberation in accordance with the Medium-Term Growth and Development Strategy (MFEA 2013).

4) Cuba

The national standard for seismic effects (NC 2017), which requires consideration of the most unfavorable conditions including wind effects, is authorized as mandatory under the Decree-Law of Standardization and Quality (CMCU 1998). However, the national standard for wind effects (NC 2003): NC 285'03 is not included under the Decree-Law.

5) Dominica

The *Physical Planning Act, 2002* (2002) requires hurricane precautions for buildings. However, the draft Building Code (PPDA 1996), which requires compliance with CUBiC'85, is not officially included under the Act. OECS-BC'16 is not mandatory either.

6) Dominican Republic

The Regulation for Wind Analysis of Structures (SEOPC 2001): RAVE'01, whose source is the US

academic society standard (ASCE 1998): ASCE 7'98, or the provisional edition (SEOPC 1980): RAVE'80 may be consulted in practice. The draft Regulation for Minimum Loads in Buildings (MOPC 2019a), which requires RAVE'01, is in the process of legislation under the *Law creating a Regulatory System for Engineering, Architecture and Related Branches* (1982). (MOPC 2019b)

7) Grenada

The ministerial order (PDA 2016), which adopts the OECS Building Code (OECS 2015): OECS-BC'15, is promulgated under the *Physical Planning and Development Control Act 2002* (2002). OECS-BC'15 also accepts CUBiC'85, BNS DPC'10, ASCE 7'05, and ASCE 7'10.

8) Haiti

The National Building Code (MTPTC 2013): CNBH'12, which requires compliance with the US model code (ICC 2009): IBC'09, is applied to projects implemented by the responsible ministry. IBC'09 requires ASCE 7'05. Revisions, adoptions and promulgations of CNBH'12 are supposed to be proceeded with in accordance with the National Disaster Risk Management Plan (MICT/MPCE 2019).

9) Jamaica

The national standard (BSJ 2017): JS 306'17, which was developed for the adoption of IBC'12, is enforced as one of the National Building Codes under the *Building Act, 2018* (2018).

10) St. Kitts and Nevis

The Building Regulations (GKN 2002): BRKN'02, which require compliance with BNS CP 28'81, are enforced under the *Development Control and Planning Act* (2002). OECS-BC'16 is not mandatory.

11) St. Lucia

The National Building Code, which follows OECS-BC'16, may be consulted in practice. The *Physical Planning and Development Act* (2005) is supposed to provide the supporting legislative framework under which the National Building Code is implemented according to the Hazard Mitigation Policy (GLC 2007).

12) St. Vincent and the Grenadines

The Building Regulations (MHVC 2008): BRVC'08, which require compliance with CUBiC'85, are enforced under the *Town and Country Planning Act, 1992* (1992). OECS-BC'16 is not mandatory.

13) Trinidad and Tobago

No regulations providing a building code are enforced under the *Planning and Facilitation of Development Act, 2014* (2014). Even for the capital, Port-of-Spain, the Building Bye-Laws (GTT 1912) do not require buildings to withstand winds. The Structural Design Guidelines (MWT 2010): SDGTT'10, which require compliance with either ASCE 7'05 or BNS CP 28'81, are required for

projects implemented by the responsible ministry.

(2) Central America

1) Belize

The Building Regulations (CBA 2022) are enforced under the *Belize Building Act* (2011), which requires hurricane precautions for buildings. However, the Regulations do not define any specific wind-resistant requirements, so IBCs are recommended by the responsible agency. (Redmond and DesRoches 2012) The Belize Building Standards were not available for this study. A wind speed based on the Saffir-Simpson Hurricane Wind Scale (NHC 2012) has been adopted in practice. (UNOPS 2016)

2) Costa Rica

The Construction Regulations: RdC'18 (INVU 2018), which are enforced under the *Urban Planning Law* (2010), do not require buildings to withstand winds. However, the representative judicial body requires compliance with regulatory provisions emanating from professional associations. (PGR 1986) Therefore, the professional association technical guidelines: LDVE'23 (CFIA 2022), which were developed using examples from ASCE 7'10, are mandatory.

3) El Salvador

The Regulations for Structural Safety of Buildings (MOPTVDU 1996), which require compliance with the professional society standard (ASIA 1997): NTDV'97, are enforced under the *Urban Planning and Construction Law* (1951). NTDV'97 was developed using examples from the Mexico City technical standards (GDF 1987): NTCV'87.

4) Guatemala

The Disaster Reduction Standard (CONRED 2010), which requires compliance with the academic society standard (AGIES 2010): AGIES NSE 2'10, is enforced under the *Law of the National Coordinator for Disaster Reduction* (1996). The source of AGIES NSE 2'10 is the US model code (ICBO 1997): UBC'97. AGIES NSE 2'10 is supplemented for dynamic effects by ASCE 7'10.

5) Honduras

The professional society standard (CICH 2008) is adopted under the *Construction Code* (2010): CHOC'08, whose source is UBC'97.

6) Mexico

Laws or regulations that define wind-resistant requirements for buildings are enforced in at least six of the 32 states. Of these, the Complementary Technical Standards (GDF 2017): NTCV'17, which were developed for Mexico City (GDF 2016), are also adopted in four states: Baja California (CBC 2018), Baja California Sur (GBCS 2005), Oaxaca (CEOTDU 2019; GOA 1998), and Tamaulipas (GTM 2012). Some definitions of NTCV'17 were based on EN'05. In addition, the Building

Regulations (GTB 1975): RCTB'75 are enforced in one state: Tabasco. Reference wind speeds for the domestic electricity sector (CFE 2020) also may be consulted in practice.

7) Nicaragua

The Construction Regulations (MTI 2007): RNC'07, whose source is the Mexico City technical standards (GDF 2004): NTCV'04, are enforced under the *Law of Organization, Competence and Procedures of the Executive Power* (2006).

8) Panama

The Structural Design Regulations (JTIA 2015): REP'14, which require compliance with ASCE 7'05, are enforced under the *Law by which the exercise of the engineering and architecture professions is regulated* (1959).

(3) Northern America

1) Canada

Either or both of the 2010 and 2015 editions of the National Building Codes (NRC 2010; 2015): NBCCA'10 and NBCCA'15, which require each user's guide (NRC 2011; 2017): UG-NBCCA'11 or UG-NBCCA'17, are accepted in all provinces and territories under respective acts and regulations. (NRC 2019)

2) United States

Any edition of the International Building Codes (ICC 2003; 2012; 2015; 2018): IBC'03, IBC'12, IBC'15, or IBC'18, which requires any edition of the academic society standards (ASCE 2002; 2010; 2016): ASCE 7'02, ASCE 7'10, or ASCE 7'16, is accepted in at least 43 of the 50 states and the District of Columbia under respective acts and regulations. (ICC 2019) Furthermore, any one of the old or new editions is also adopted in five unincorporated territories. Of these, in American Samoa, the *Uniform Building Code* (1969), which requires compliance with the Uniform Building Code (ICBO 1964): UBC'64, is enforced as a public law. However, the Code does not define any authorized wind-pressure-map area for UBC'64. The source of UBC'64 is the US national standard (ASA 1955): ANSI A.58.1'55. In Guam and Northern Mariana Islands, the *Building Code* (2010): BCGU'10 and the *Building Safety Code Rules and Regulations* (2009): BSCRR'09, respectively, both of which require compliance with the International Building Code (ICC 2009): IBC'09, are regarded as a public law. IBC'09 requires ASCE 7'05. In the Virgin Islands, the *Building Code* (2018): BCVI'18, which requires compliance with IBC'03 and any subsequent updates, is enforced as a public law. In Puerto Rico, the Building Code (PRCCC 2018): BCPR'18, which was developed for the adoption of IBC'18, is enforced under the *Law for the Reform of Permitting Process* (2009).

(4) South America

1) Argentina

The National Safety Regulations for Civil Works (SOP 2012), which include the Regulation of Wind

Action on Constructions (CIRSOC 2005): CIRSOC 102'05, are enforced in accordance with the presidential decree (PAR 2003), which establishes the powers of the responsible ministry. The source of CIRSOC 102'05 is ASCE 7'98.

2) Bolivia

The Code of Urban Planning and Works (GSS 2015), which accepts both the municipal and national standards (CICS 2012; IBNORCA 2015): CIC 103'12 and NB 1225003'14, is made mandatory in metropolitan Santa Cruz de la Sierra under the *Framework Law on Autonomy and Decentralization* (2010). Both sources are CIRSOC 102'05.

3) Brazil

The Simplified Works and Buildings Code (GRJ 2019), which requires compliance with national standards including the national standard for wind forces (ABNT 2013): NBR 6123'13, is enforced to supplement the ordinary and complementary laws for metropolitan Rio de Janeiro (GRJ 1990; 2011).

4) Chile

The General Ordinance of Urban Planning and Constructions (MVU 2017), which requires design reviews through the withdrawn national standard (INN 1971): Nch 432'71, is enforced under the *General Law of Urban Planning and Constructions* (2017). The current national standard (INN 2010): Nch 432'10, whose source is ASCE 7'05, is not mandatory.

5) Colombia

The Seismic Resistant Construction Regulations (MAVDT 2010): NSR'10, which also define wind forces, are enforced under the *Law by which norms on Earthquake Resistant Constructions are adopted* (1997). The source of NSR'10 is ASCE 7'05.

6) Ecuador

The ministerial agreement (MIDUVI 2015a), which endorses the Construction Standard (MIDUVI 2015b): NEC-SE-CG'14, is concluded in accordance with the Statute of Administrative Legal Regime of the Executive Function (PCEC 2018). NEC-SE-CG'14 was developed using examples from the Peruvian national regulations (MVCS 2006): RNE'06.

7) Guyana

Even for the capital, Georgetown, the Building By-laws (GTTC 1946) do not require buildings to withstand winds. The UK national standard (CCPB 1952): BS CP3 CV'52 or CUBiC'85 has been consulted in practice. (Caballero 2018; Deodharry 2018) The Building Code for Structural Steel (GNBS 1999), which accepts both US and other UK national standards, is not mandatory. The By-laws are under review based on the National Building Codes (GNBS 2016). (Ahamad 2020)

8) Paraguay

The General Construction Regulations (JMA 1991), which require compliance with national standards including the national standard for wind actions (INTN 1991): NP 196'91, are enforced in the capital, Asuncion, under the *Municipal Organic Law* (2010). NP 196'91 was developed using examples from the Brazilian national standard (ABNT 1988): NBR 6123'88.

9) Peru

The National Building Regulations (MVCS 2006): RNE'06 are enforced under the *Law of Organization and Functions of the Ministry of Housing, Construction and Sanitation* (2002).

10) Suriname

The *Building Ordinance* (1956) and Decree (RSR 1956): BB1'56, which were enacted at the time of the Dutch constituent country, are still enforced. The Dutch national standard (NEN 2007): NEN 6702'07 may also be consulted in practice. (MOW 2014)

11) Uruguay

Even for the capital, Montevideo, the Departmental Regulations (IMO 2017) do not define any structural safety requirements for buildings. The national standard (UNIT 1994): UNIT 50-84'94 is required for projects implemented by the responsible ministry. (MTOP 2006)

12) Venezuela

The national standard for seismic effects (FONDONORMA 2001), which requires consideration of the national standard for wind effects (COVENIN 1989): COVENIN 2003'89, is made mandatory under the *Organic Law of the National System for Quality* (2002). COVENIN 2003'89 was developed using examples from ANSI A58.1'82.

2.2.3 Asia

(1) Central Asia

1) Kazakhstan

The list of normative documents (MIID 2020), which includes EN'05 with the national annex (CCHULM 2015): SN EN NA'11, is issued under the *Law on Architectural, Urban Planning and Construction Activities* (2001). (MNE 2015)

2) Kyrgyzstan

The order from the responsible state agency (Gosstroy 2012), which endorses the Russian (RU) national standard (USSR Gosstroy 2005): SNiP 2.01.07'05, is promulgated under the *Law on Technical Regulations "Safety of Buildings and Structures"* (2011).

3) Tajikistan

The governmental decree (GTJ 2009), which endorses SNiP 2.01.07'05, is promulgated for compliance with the *Law on Technical Regulations* (2009a).

4) Turkmenistan

The Construction Norms (MCA 2017), which include the ministerial standard (MCBMI 2005): TGK 2.01.07'05, apply under the *Law on Architectural Activity* (2017). The source of TGK 2.01.07'05 is the RU national standard (USSR Gosstroy 1988): SNiP 2.01.07'88.

5) Uzbekistan

The list of normative documents (Gosarkhitektstroy 2018), which includes the national standard (Gosarkhitektstroy 1996): KMK 2.01.07'96, is issued under the *Law on Technical Regulations* (2009b). The source of KMK 2.01.07'96 is SNiP 2.01.07'88.

(2) Eastern Asia

1) China

The national standard (MHURD 2012): GB 50009'12 is enforced as one of the compulsory standards under the *Standardization Law* (2017). At the same time, legislation is independently implemented in two special administrative regions. Of these, in Hong Kong, the Building (Construction) Regulations (GHK 2012a) are enforced under the Buildings Ordinance (GHK 2012b). Compliance with the Regulations is established through the Practice Notes (BD 2009), which accept the Code of Practice on Wind Effects (BD 2019): CPWEHK'19. In Macau, the existing Regulations on Safety and Actions in Structures of Buildings and Bridges (GMO 1996): RSAEEP'96, have not yet been superseded by the revised edition (LECM 2008): RSAEEP'08. Some definitions of RSAEEP'08 were based on the Australian (AU) and New Zealand (NZ) joint standard (AS/NZS 2002): AS/NZS 1170.2'02. In Taiwan, the Building Technical Regulations (MITW 2016): BTRTW'16, which require compliance with the Specifications for Wind Resistant Design of Buildings (CPAMI 2014): SCBWRD'14, are enforced under the *Building Act* (2011). Some definitions of SCBWRD'14 were based on ASCE7'98.

2) Japan

The Building Standard Law Enforcement Order (CJP 2008): BSLEO'08, which accepts two ministerial stipulations (MCJP 2000a; b): BSLN 1454'00 and BSLN 1458'00, is promulgated under the *Building Standard Law* (2000). These stipulations were developed using examples from the academic society standard (AIJ 1993): AIJ-RLB'93. The academic society standard (AIJ 2015): AIJ-RLB'15 is not mandatory.

3) Mongolia

The Code on Loads and Reactions (MRTCUD 2009): BNbD 20-04'17, whose source is the RU code of practice (MCIHUS 2011): SP 20.13330'11, as well as the Climatic and Geophysical Parameters for

Construction (MCUD 2017): BNbD 23-01'09, becomes a part of the General System of Norms and Normative Documents for Construction (GMN 2019) under the *Law on Construction* (2016). The national standard (MASM 1981): MNS 3177'81 or EN'05 is not mandatory.

4) North Korea

The full text of the wind load standard: BSSKP'ND, which the national construction supervision agency apparently prepared under the *Construction Act* (2011), was not accessible for this study. (KICT 2019) In the special economic zones: Hwanggumphyong or Wihwado, advanced standards of design technique or technical norms of foreign countries may be introduced to building designs. (PSPA 2001)

5) South Korea

The Building Structural Standards Rules (MLTMA 2009), which require compliance with the Building Structural Standards (MLTMA 2019): KDS 41 10 15'19, are enforced under the *Building Law* (2019). Some definitions of KDS 41 10 15'19 were based on AIJ-RLB'93.

(3) South-eastern Asia

1) Brunei

The Building Control Regulations (MD 2014) are enforced under the *Building Control Order, 2014* (2014). Compliance with the Regulations is established through the Building Guidelines and Requirements (ABCi 2017), which accept BS CP3 CV2'72, the UK national standard (BSI 1997): BS 6399.2'97 and EN'05 with BS EN NA'10. For BS EN NA'10, a reference wind speed based on wind speed records from past thunderstorms may be consulted in practice. (Kite et al. 2014)

2) Cambodia

No building technical regulations that define structural safety requirements for buildings are enforced under the *Law on Construction* (2019). The use of the US model code (ICC 2006): IBC'06, which requires ASCE 7'05, has been recommended by the governmental authority. (BEC 2016) Statistically analyzed wind speeds (Lin et al. 2022; MoIME 2007; Vong et al. 2022) or a reference wind speed based on wind tunnel tests (MLIT 2015) may be consulted in practice.

3) Indonesia

The Implementing Regulations (GID 2005) are enforced under the *Law on Buildings* (2002). Compliance with the Regulations is established through the Guidelines for Building Technical Requirements (KPU 2006), which accept the withdrawn national standard (KPU 1989): SNI 03-1727'89. The current national standard (BSN 2013): SNI 1727'13, whose source is ASCE 7'10, is not mandatory. However, in the capital, Jakarta, SNI 1727'13 and a reference wind speed based on consensus among authorities have been consulted in practice. (Setiadi 2015)

4) Laos

Development of the Building Code is in progress under the *Construction Law* (2009). The draft Building Code (MPWT 2016): BCLA'16 remains incomplete in studying wind effects. Statistically analyzed wind speeds (ADPC 2010) or study results (JICA 2002) may be consulted in practice.

5) Malaysia

Ordinances or by-laws that define wind-resistant requirements for buildings are enforced in at least five of the 16 states and federal territories under the *Street, Drainage and Building Act 1974* (1974). Of these, the Uniform Building By-Laws (ILBS 2013), which require compliance with BS CP3 CV2'72, are adopted in two states and federal territories: Johor (GJH 2012) and the Federal Territory of Kuala Lumpur (MFT 1985). The Buildings Ordinance (GSW 2008), which requires compliance with BS 6399.2'97, is enforced in one state: Sarawak. The Uniform Building By-Laws, which require compliance with the national standard (DSM 2002): MS 1553'02, are enforced in two states: Melaka (MLG 2019) and Selangor (GSG 2012). MS 1553'02 was developed according to the format of the AU and NZ joint standard: AS/NZS 1170.2s. EN'05 is not mandatory.

6) Myanmar

Even for metropolitan Yangon, the Building Regulations (YCDC 2014) do not require any structural requirements for buildings. The National Building Code (MCOMM 2020): NBCMM'20, whose source is ASCE 7'05, may be consulted in practice. The Construction Industry Development Board Law, which establishes an organization for setting standards for the construction industry, is still in the bill stage. (EUROCHAM 2019)

7) Philippines

The National Building Code (PPH 2005), which requires compliance with the professional society code (ASEP 2015): NSCP C101'15, is enforced in accordance with its Implementing Rules and Regulations (NBCDO 2005). The source of NSCP C101'15 is ASCE 7'10.

8) Singapore

The Building Control Regulations (MND 2003) are enforced under the *Building Control Act* (2015). Compliance with the Regulations is established through the Approved Document (BCA 2019): BCRA'19, which accepts BS CP3 CV2'72, BS 6399.2'97 and EN'05 with the national annex (SPRING-SG 2009): SS EN NA'09.

9) Thailand

The ministerial regulations (MITH 1984): BCAR6'84 are enforced under the *Building Control Act* 2522 (1979). The ministerial standard (DPWTP 2007): DPT 1311-50'07, which was developed using examples from the Canadian model code (NRC 2005): NBCCA'05, is not mandatory.

10) Timor-Leste

The proposed Building Code (VCG 2003): BCTL'03, which requires the Australian (AU) national standard (AS 1993): AS 1170.2'89, has not been enshrined into law. (Maturana 2003) Therefore, SNI 1727'13 has been consulted in practice. (MPW 2016) Statistically analyzed wind speeds (ADPC 2012) may be consulted in practice.

11) Vietnam

The Building Code (MCVN 1997): BCVN'97, which requires compliance with the national standard (MST 1996): TCVN 2737'96, as well as the National Technical Regulations (MCVN 2009): QCVN 02'09, is enforced in accordance with the governmental decree (GVN 1994), which establishes the functions and tasks of the responsible ministry. TCVN 2737'96, which was compiled on the basis of SNiP 2.01.07-85'88, is supplemented for dynamic effects by the ministerial standard (MCVN 1999): TCXD 229'99. The draft national standard (MST 2020): TCVN 2737'20, some definitions of which were based on ASCE 7s, has not yet been endorsed as mandatory for compliance with the Code. EN'05 is not mandatory either. However, the plan for completing the national standard system oriented to the EU standard system is under way. (MCVN 2022)

(4) Southern Asia

1) Afghanistan

The Structural Code (ANSA 2012): ASC'12, whose source is ASCE 7'10, may be consulted in practice. For the capital, Kabul, IBC'12 may also be accepted in accordance with the Building Standards Policy (KBM n.d.).

2) Bangladesh

The National Building Code (MHPW 2020): NBCBD'20, which was developed using examples from ASCE 7'05, is enforced under the *Building Construction Act, 1952* (1953).

3) Bhutan

The Building Regulation (MWHS 2018a) is enforced under the *Local Government Act, 2009* (2009). Compliance with the Regulation is established through the Building Code (MWHS 2018b): BCBT'18, which accepts the Indian national standard (BIS 2007): IS 875.3'87. A reference wind speed has been defined in the ministerial standard (NACSQC 2003): BTS-002'03.

4) India

Bye-laws or rules that define wind-resistant requirements for buildings are enforced in at least eight of the 36 states and union territories. Of these, the National Building Code (BIS 2016): NBCIN'16 or the national standard (BIS 2015): IS 875.3'15 is adopted in six states and union territories: Andhra Pradesh (GAP 2017), Karnataka (GKA 2017), Maharashtra (GMH 2018), Tamil Nadu (GTN 2019), West Bengal (GWB 2007), and the National Capital Territory of Delhi (DDA 2016). The withdrawn National Building Code (BIS 2005): NBCIN'05 or the withdrawn national standard (BIS 2007): IS

875.3'87 is still enforceable in two states: Bihar (BUDHD 2014) and Jharkhand (JUDHD 2016).

5) Iran

Compliance with the National Building Regulations (NBCRO 2013): NBRIR'13, whose source is NBCCA'10, is deemed to be equivalent to compliance with the *Law on Engineering System and Building Control* (1995). The national standard (ISIRI 1996): ISIRI 519'96 is not mandatory.

6) Maldives

The National Building Code (MCPI 2008), which requires buildings to withstand winds, is enforced under the *Construction Act* (2017). The draft Approved Document (MCPI 2007), which accepts BS 6399.2'97, has not yet been endorsed as mandatory for compliance with the Code. Therefore, BS CP3 CV2'72 has hitherto been consulted in practice instead of BS 6399.2'97. (HDC 2015) Statistically analyzed wind speeds (UNDPMV 2006) may be consulted in practice.

7) Nepal

The National Building Code (MPPW 2008): NBCNP 104'94, which requires compliance with IS 875.3'87, is enforced under the *Building Act, 2055 (1998)* (2006).

8) Pakistan

Regulations or bye-laws that accept one or more of the US model codes, the UK national standards, or the ministerial code (MHW 2007): BCP-SP'07 are enforced in at least five of the seven provinces, and autonomous and federal territories. For example, BS CP3 CV'52 or BCP-SP'07 is accepted in one federal territory: the Islamabad Capital Territory (CDA 1963; 2019), and the US model codes or the UK national standards approved by the responsible authority are commonly accepted in two provinces: Khyber Pakhtunkhwa (LGERDD 2017) and Sindh (HTPD 2002). In one province: Punjab, where multiple responsible authorities are established, the requirements of UBC'97, IBC'06, or BCP-SP'07 shall be met in metropolitan Lahore (LDA 2019). In one autonomous territory: Azad Jammu and Kashmir, BCP-SP'07, UBC'97, IBC'03, or IBC'06 shall apply with proper engineering judgment. (JICA 2008) BCP-SP'07 was developed using examples from UBC'97.

9) Sri Lanka

Even for the former capital, Colombo, the Planning and Building Regulations (UDA 2018) do not require buildings to withstand winds. EN'05 with the national annex (SLSI 2016): SLS EN NA'16 may be consulted in practice. However, the ministerial guidebook (MLGHC 1980): DBHW'80, which requires compliance with BS CP3 CV2'72, is directed to be adopted for public works. (CIDA 2004) Initiatives to strive to develop the first National Building Code are continuing in accordance with the Cabinet of Ministers decisions. (WB 2020)

(5) Western Asia

1) Armenia

The Normative Acts Regulations (MUD 2001), which require compliance with SNiP 2.01.07'88, as well as the Construction Norms on Climatology (MUD 2011): HHSN II-7.01'11, are enforced under the *Law on Urban Development* (1998).

2) Azerbaijan

The list of normative documents (FHN/ARXKOM 2019), which includes the construction standard (ARXKOM 2015): AzDTN 2.1-1'15, is issued under the *Urban Building and Construction Code* (2014). The source of AzDTN 2.1-1'15 is SP 20.13330'11.

3) Bahrain

The Building Regulations Law (GBH 1977) does not define any structural safety requirements for buildings. More comprehensive requirements of the Gulf Cooperation Council, Saudi Arabia, or the UK may be accepted in accordance with the Unified Guidebook of Building Permit Regulations (GBH 2020). No information about codes or standards was available for this study, except for the outdated information that BS 6399.2'97 and a reference wind speed based on consultation with authorities had once been consulted in practice. (Khan and Halford 2008)

4) Cyprus

The Road and Building Regulations (CMCY 2011), which require compliance with EN'05 with the national annex (CYS 2010): CYS EN NA'10, are enforced under the *Road and Building Regulations Law* (1959).

5) Georgia

The Construction Norms and Rules (MESD 2011), which require compliance with SNiP 2.01.07'88, as well as the Design Norms on Construction Climatology (MESD 2008): PN 01.05'08, are enforced under the *Law on Normative Acts* (2009) and the *Law on Construction Activities* (2000), respectively. EN'05 is not mandatory.

6) Iraq

The Code of Loads and Forces (COSQC 2016): MBO 301'15, whose source is BS CP3 CV2'72, is enforced as one of the Building Codes under the *Law on Central Organization for Standardization and Quality Control* (1979).

7) Israel

The Planning and Building Regulations (MIIL 1970), which require compliance with the national standard (SII 2009): SI 414'08, are enforced under the *Planning and Building Law, 5725-1965* (1965). SI 414'08 was developed using examples from EN'05.

8) Jordan

The National Building Code (NCCJ 2006): NBCJO'06, which was developed using examples from BS 6399.2'97, is enforced in accordance with the Instructions of Codes Application (NCCJ 2005) under the *National Construction Law* (1993).

9) Kuwait

The Building Regulations (KM 1985) do not define any structural safety requirements for buildings. ASCE 7'05 and statistically analyzed wind speeds (KISR 2013) have been consulted in practice. (Neelamani 2018)

10) Lebanon

The Public Safety Law (CMLB 2012), which accepts standards and specifications of EU countries, the US, or Canada, is enforced under the Construction Law (GLB 1983). The national standard (LIBNOR 2013): NL 137'13, which defines reference wind speeds, as well as any of UBC'97, IBC'09, the FR technical document (CSTB 2009): NV 65'09, or EN'05 with NF EN NA'08, may be consulted in practice.

11) Oman

Even for the capital, Muscat, the Building Regulation (MAM 1992) does not require buildings to withstand winds. BS 6399.2'97 and statistically analyzed wind speeds (Alnuaimia et al. 2014) may be consulted in practice. The Structural Guidelines (OPAZ 2022), which require compliance with ASCE 7s, may be consulted in the special economic zone at Duqm.

12) Palestine

The Regulation on Multistory Buildings (PNA 1994), which requires buildings to withstand winds, is enforced in the Gaza Strip under the Town Planning Law (PNA 1936). However, the Regulation does not define any specific wind-resistant requirements. Local practices based on IBC'12 may be consulted in practice. (Ziara 2018)

13) Qatar

The Construction Specifications (MEQA 2014): QCS'14, which accept ASCE 7'05, IBC'12, BS 6399.2'97, and EN'05 with BS EN NA'10, are enforced under the *Law on Building Regulations* (1985).

14) Saudi Arabia

The Building Code (SBCNC 2018): SABC 301'18, whose source is ASCE 7'10, is enforced in accordance with the Implementing Regulations (SBCNC 2017).

15) Syria

The Building Code (DGC 1997) is enforced in the capital, Damascus, under the Local Administration Law (GSY 2011). Compliance with the Code is established through the professional society codes

(SEA 2006; 2012) SYBC'12 or SYBC-1'06. SYBC-1'06 was developed using examples from BS CP3 CV2'72.

16) Turkey

The Regulation on Buildings to be Built in Earthquake Regions (MPWHT 2007), which requires consideration of the most unfavorable conditions of seismic or wind effects, is enforced under the Law on Aid and Measures to be taken due to Disasters affecting Public Life (CMTR 1969). However, the Regulation does not define any specific wind-resistant requirements. The ministerial regulation for steel structures: SSR'16 (MEUC 2016), which requires compliance with the national standard (TSE 1997): TS 498'97, is enforced in accordance with the decree law (CMTR 2011), which regulates the duties of the responsible ministry. SSR'16 defines that EN'05 supplements TS 498'97, which was developed using examples from the German (DE) national standard (DIN 1986): DIN 1055-4'86 The municipal regulation: IYBRY-V'09 (IBBIM 2009), which was developed using examples from EN'05, may be consulted for high-rise buildings over 60 m in height (IBBIM 2008) in metropolitan Istanbul. However, IYBRY-V'09 is not mandatory.

17) United Arab Emirates

Codes or regulations that define wind-resistant requirements for buildings are enforced in at least three of the seven emirates. Of these, the Building Codes: ADIBC'13 for Abu Dhabi (GAE 1983; 2014) and RAKBC'18 for Ras Al Khaimah (GRK 2018) both require compliance with ASCE 7'05. In Dubai, the municipal regulations (GDU 2001) and circular (GDU 2013a): DUSCG'13 accept the municipal Wind Code (GDU 2013b): DUWC'13, BS 6399.2'97, and ASCE 7'05 and its subsequent editions. DUWC'13 was developed using examples from EN'05.

18) Yemen

The Implementing Regulations for the Construction Law (MPWHY 2008) do not require buildings to withstand winds. No information about codes or standards was available for this study, except for the outdated information that UK national standards or US model codes had once been consulted in practice. (JICA 2006) Study results in wind speed records (Al-Zafairi 2007) may be consulted in practice.

2.2.4 Europe

(1) Eastern Europe

1) Belarus

The Building Code (MAS 2020): CH 2.01.05'19 is stipulated as one of the technical regulatory legal acts by the ministerial resolution (MAS 2019) in accordance with the Decree on Building Codes and Regulations (PBY 2019). The source of CH 2.01.05'19 is EN'05.

2) Bulgaria

2 ministerial ordinances for structural design of buildings (MRDPW 2004; 2011): MRDPW'04 and MRDPW'11 are enforced under the *Spatial Development Act* (2001). The source of MRDPW'04 is SNiP 2.01.07'88. MRDPW'11 requires compliance with EN'05 with the national annex (BDS 2011): BDS EN NA'11.

3) Czech

The Decree on Technical Requirements for Construction (MRD 2009), which requires compliance with EN'05 with the national annex (UNMZ 2013): CSN EN NA'13, is promulgated under the *Building Act (Act on Territorial Planning and Building Regulations)* (2006).

4) Hungary

The Decree on National City Planning and Construction Requirements (GHU 1997), which requires compliance with EU standards including EN'05 with the national annex (MSZT 2007): MSZ EN NA'07, is promulgated under the *Law on Design and Protection of the Built Environment* (1997).

5) Moldova

The ministerial order (MEIMD 2019), which endorses SNiP 2.01.07'88, is promulgated for enforcement of the *Law on Quality in Construction* (1996). EN'05 with the national annex (ISM 2018): SM EN NA'18 is not mandatory.

6) Poland

The Regulation on Technical Conditions (MIDPL 2019), which requires compliance with EU standards including EN'05 with the national annex (PKN 2010): PN EN NA'10, is enforced under the *Building Law* (1994).

7) Romania

The Technical Regulation (MRDT 2012): CR 1-1-4'12 is enforced under the *Law on Quality in Construction* (1995). EN'05 with the national annex (ASRO 2007): SR EN NA'07 is not mandatory.

8) Russia

The ministerial order (MCIHUS 2017), which endorses the code of practice (MCIHUS 2016): SP 20.13330'16, is promulgated under the *Federal Law on Technical Regulation on Safety of Buildings and Structures* (2002). SP 20.13330'16 is supplemented for dynamic effects by the authorized recommendations (TsNIISK 2000): TsNIISK'00. EN'05 with the national annex (MCIHUS 2014): SP 201.1325800'14, which was developed using examples from SP 20.13330'11, is not mandatory.

9) Slovakia

The Decree on General Technical Requirements (MZP 2002), which requires compliance with EU standards including EN'05 with the national annex (SSI 2008): STN EN NA'10, is promulgated under

the *Act on Spatial Planning and Building Regulations (Building Act)* (1976).

10) Ukraine

The ministerial order (MRDCHCS 2013), which endorses EN'05 with the national annex (PNTU 2010): DSTU EN NA'10, is promulgated under the *Law on Building Codes* (2013).

(2) Northern Europe

1) Denmark

The Building Regulations (TBHA 2018), which require compliance with EN'05 with the national annex (DSF 2015): DS EN NA'15, are enforced under the *Building Act* (2010a). At the same time, legislation is independently implemented in two autonomous territories. Of these, in the Faroe Islands, the Building Regulations (Landsverk 2017): BK'17, which require compliance with EN'05 with DS EN NA'15 and the review report (DMI 2001): DMI'01, are enforced under the *Law on Building Construction* (2012). BK'17 also accepts the national standard (DSF 1982): DS 410'82. In Greenland, the Building Regulations (GGL 2006), which require compliance with the Regulations for Loads on Structures (BAGL 1995): FLK'95, are enforced under the *Building Act* (2010b). FLK'95 also requires compliance with DS 410'82. EN'05 with the territorial annex (IAAN 2010): GL EN NA'10 is not mandatory.

2) Estonia

The Regulation on Requirements for Construction Projects (MEAC 2010) does not require buildings to withstand winds. The ministerial standard (MEEE 1996): EPN-ENV 1.2.6'96 or EN'05 with the national annex (EVS 2007): EVS EN NA'07 may be consulted in practice. The source of EPN-ENV 1.2.6'96 is ENV'95.

3) Finland

The Decree on Load-bearing Structures (YM 2014), which requires compliance with EN'05 with the national annexes (YM 2010; 2016): SFS EN NA'10 and SFS EN NA'16, is promulgated under the *Land Use and Building Act* (2012). In the autonomous territory: the Åland Islands, the Building Regulations (ALR 2015), which require compliance with EN'05 with SFS EN NA'10 and SFS EN NA'16, are enforced under the *Planning and Building Act* (2008).

4) Iceland

The Building Regulations (MENR 2018), which require compliance with EU standards including EN'05 with the national annex (IST 2010): IST EN NA'10, are enforced under the *Planning and Building Act* (1999).

5) Ireland

The Building Regulations (DHPLG 2012a) are enforced under the *Building Control Act 2007* (2007). Compliance with the Regulations is established through the Technical Guidance Document (DHPLG

2012b), which accepts EN'05 with the national annex (NSAI 2013): IS EN NA'13. The source of IS EN NA'13 is BS EN NA'10.

6) Latvia

Regulations for each structure type, such as the Regulations on Design of Steel Structures (CMLV 2014), which require compliance with EU standards including EN'05 with the national annex (LVS 2011): LVS EN NA'11, are enforced under the *Construction Law* (2013).

7) Lithuania

The Construction Technical Regulation (MELT 2003): STR 2.05.04'03, whose source is SNiP 2.01.07'88, is enforced under the *Construction Law* (2002). EN'05 with the national annex (LST 2012): LST EN NA'12 is not mandatory.

8) Norway

The Building Technical Regulations (KMD 2017), which require compliance with EU standards including EN'05 with the national annex (SN 2010): NS EN NA'09, are enforced under the *Planning and Building Act* (2008). The same is true for the administrative center, Longyearbyen, in Svalbard, which forms an unincorporated internal area. (JD 2017)

9) Sweden

The Planning and Building Regulation (MEISE 2011), which requires compliance with EN'05 with the national annex (Boverket 2019): EKS 11'19, is enforced under the *Planning and Building Act (2010: 900)* (2010).

10) United Kingdom

The Building Regulations (DCLG 2010; NIE 2012; STG 2004) are enforced in four constituent countries under the *Building Act 1984* (1984). Compliance with the respective Regulations is established through EN'05 with the national annex (BSI 2010): BS EN NA'10 in England (HMG 2013), Northern Ireland (DLGC 2016), and Scotland (DFP 2012), or the national standard (BSI 1997): BS 6399.2'97 in Wales (WLG 2017). Similarly, seven overseas territories and three Crown Dependencies also have their own legislation. Of these, four overseas territories in the West Indies follow one or two of IBCs, ASCE 7s, or CUBiC'85. Specifically, in Bermuda, the Building Code (MEP 2014): BCBM'14, which requires compliance with IBC'12, is enforced under the *Building Act 1988* (1988). In the Cayman Islands, the Building Code (CCI 2016): BCRKY'16, which requires compliance with IBC'09, is enforced under the *Development and Planning Law (2015 Revision)* (2015). In the Turks and Caicos Islands, the Building Code (MEHA 2014): BCTC'14, which requires compliance with ASCE 7'05, is accepted under the Physical Planning Ordinance (GTC 1989). (GTC 1990) In the Virgin Islands, the Building Regulations (VGPWD 1999), which require compliance with CUBiC'85, are enforced under the Buildings Ordinance (GVG 1955). However, OECS-BC'16 is not mandatory. In the Falkland Islands, the Building Regulations (FKG 2000), which require

buildings to withstand winds, are enforced under the Building Control Ordinance (FKG 1994). However, the Regulations do not define any specific wind-resistant requirements. BS 6399.2'97 and a reference wind speed recommended by authorities have been consulted in practice. (Burrows 2018) The remaining two overseas territories follow the national or EU standards. Specifically, in Gibraltar, the Building Rules (GGI 2017): BRGI'17, which require compliance with the national standard (BSI 1972): BS CP3 CV2'72, are enforced under the *Public Health Act* (1950). Only in St. Helena excluding Ascension and Tristan da Cunha, the Building Regulations (SHG 2019), which require compliance with EN'05 with BS EN NA'10, are enforced under the Building Control Ordinance (SHG 2013). However, no authorized reference wind speed was identified in this study. The same is mostly true for three Crown Dependencies. In Guernsey, compliance with the Building Regulations (ED 2012) is established through the Technical Standard (ED 2017), which accepts EN'05 with BS EN NA'10, under the *Land Planning and Development (Guernsey) Law, 2005* (2005). In the Isle of Man, compliance with the Building Control Order (DI 2019) is established through the Approved Document (HMG 2013), which also accepts EN'05 with BS EN NA'10, under the *Building Control Act 1991* (1991). In Jersey, compliance with the Building Bye-Laws (DPE 2015) is established through the Technical Guidance Document (PEC 1997), which accepts BS CP3 CV2'72, under the *Planning and Building (Jersey) Law 2002* (2002). Meanwhile, two overseas territories in the West Indies have draft building codes. Of these, in Anguilla, neither the Building Code (MIAI 2019), which requires compliance with CUBiC'85, nor OECS-BC'16 has been enshrined into law. Even in Montserrat, OECS-BC'16 has not yet been enacted.

(3) Southern Europe

1) Albania

The Standards and Technical Conditions (CMAL 2001): KTP 7'78, which require compliance with the Technical Design Conditions (MCAL 1978), are enforced under the *Law on Control and Discipline of Construction Works* (1988). EN'05 is not mandatory.

2) Andorra

The Construction Regulations (GAD 2003) do not require buildings to withstand winds. CTE DB-SE-AE'09 had once been consulted in practice. (Bonell 2008) The ministerial standard (CSP 1989): CSP'89, which was developed using examples from NV 65s, may also be consulted in practice.

3) Bosnia and Herzegovina

Laws or regulations that define wind-resistant requirements for buildings are enforced in two of the three political divisions. The national standard (FBS 1988): TNO'88 and the ministerial regulations (MITYU 1964): TPV'64, both of which were developed at the time of Yugoslavia, are accepted in the Federation of Bosnia and Herzegovina (FMPP 2008; GBIH 2008) and in Republika Srpska (GSRP 2013). TNO'88, which only declaratively defines wind actions, does not define any specific wind-resistant requirements. TPV'64 was developed with reference to the DE national standard (DIN 1938): DIN 1055-4'38. EN'05 with the national annex (ISBIH 2018): BAS EN NA'18 is not

mandatory.

4) Croatia

The Technical Regulation for Building Structures (MCSP 2017), which requires compliance with EN'05 with the national annex (HZN 2014): HRN EN NA'14, is enforced under the *Building Act* (2019).

5) Greece

Parallel use of the Load Regulation on Construction Works (GSPW 1945): BLR'45 and EN'05 with the national annex (ELOT 2010): ELOT EN NA'10 is enforced in accordance with the common ministerial decision (MDC/MITN/MEEC 2014), which applies EU standards.

6) Holy See

The *Law on Sources of the Law* (1929) makes provision for the supplementary application of laws promulgated by Italy, such as the Italian technical standards (MITIT 2018): NTC'18.

7) Italy

The Technical Standards for Construction (MITIT 2018): NTC'18 are enforced in accordance with the presidential decree (PIT 2001), which consolidated building laws and regulations. EN'05 with the national annex (MITIT 2012): UNI EN NA'07, as well as the authorized guidebook (CNR 2010): CNR-DT 207'08, is not mandatory.

8) Malta

The Building Regulations, which define structural safety requirements for buildings, have not yet been enforced under the *Building Regulation Act* (2011). EN'05 and a reference wind speed recommended by authorities have been consulted in practice. (Camilleri 2015) Consolidation and review of laws and regulations in the form of the national building code based on EU standards is underway in accordance with the governmental order (GMT 2019), which defines the powers of the responsible agency. (Kamra Tal-Periti 2020)

9) Montenegro

Rulebooks for each structure type, such as the Rulebook on Technical Requirements for Steel Structures (MSDT 2018), which accept TNO'88, TPV'64, and EN'05 with the national annex (ISME 2016): MEST EN NA'16, are issued under the *Law on Spatial Development and Construction of Structures* (2018).

10) North Macedonia

The Rulebook for supplementing the Rulebook on Design Standards and Norms (MTC 2020), which accepts the national standard (ISRM 1991): MKC U.C7.110'91 and EU standards including EN'05 with the national annex (ISRM 2020): MKC EN NA'20, is issued under the *Building Law* (2009).

11) Portugal

The General Regulation of Urban Buildings (MOP 1951) requires building walls to withstand winds. However, the Regulation does not define any specific wind-resistant requirements. The order from the responsible secretary of state (GSEI 2019), which approved the conditions for using EU standards including EN'05 with the national annex (IPQ 2010): NP EN NA'10, is promulgated in consideration of the decree-law (GPT 2019), which establishes the regime applicable to building rehabilitations. The order also accepts the repealed Regulation of Security and Actions for Building Structures and Bridges (MHOPT 1983): RSA'83 during 3-year transition period.

12) San Marino

The Implementing Regulations (GSM 2015): NA-181'15, which require compliance with NTC'18, are enforced under the *Law on Structural Design* (2011).

13) Serbia

The Rulebook for Building Structures (MCTI 2019), which requires compliance with EN'05 with the national annex (ISS 2017): SRPS EN NA'17, is issued under the *Law on Planning and Construction* (2009).

14) Slovenia

The Rulebook on Mechanical Resistance and Stability of Buildings (MESP 2006), which requires not less than wind effects determined in accordance with EN'05 with the national annex (SIST 2008): SIST EN NA'08, is issued under the *Building Construction Act* (2005).

15) Spain

The Technical Building Code (MV 2006), which includes the Basic Document for Structural Safety (MV 2009): CTE DB-SE-AE'09, is enforced under the *Building Act* (1999). CTE DB-SE-AE'09 was developed using examples from EN'05. EN'05 is not mandatory.

(4) Western Europe

1) Austria

Either the 2015 or 2019 edition of the professional society guidelines (OIB 2015; 2019) is enforced in all states under respective acts and regulations. (OIB 2020) However, not even the 2019 edition, which requires non-bearing walls such as curtain walls to withstand winds, mandates EN'05 with the national annex (ASI 2013): ONORM EN NA'13.

2) Belgium

Even in the capital, Brussels, the Building Regulations (BVM 1921) do not require buildings to withstand winds. EN'05 with the national annex (NBN 2010): NBN EN NA'10 is required for public procurement in one of the three regions: Wallonia. (GWL 2016)

3) France

Compliance with construction rules for storm or cyclonic risks defined in the Foreseeable Natural Risks Prevention Plan (PPRN), which was developed for each municipality under the *Environmental Code* (2018), is required under the *Construction and Housing Code* (2006). For 96 departments of Metropolitan France, compliance with the Unified Technical Documents: NV 65s is required for wind-related risks in specific small municipalities of at least three departments: Alpes-de-Haute-Provence (SE04 2021), Isère (SE38 2021) and Pyrenees-Atlantiques (SE64 2021). However, no specific rule for wind-related risks is identified in most municipalities of other departments. In at least two major departments: Bouches-du- Rhône (P13 2021) and Nord (P59 2011), however, NV 65'00 is not mandatory but is available as a rule for storm risks. For five overseas departments, compliance with any edition of NV 65s is required for wind-related risks in most municipalities of three overseas departments: Guadeloupe (SEGP 2020), Martinique (DEAL 2018) and Réunion (SERE 2018). As described above, no municipality that requires compliance with EN'05 with the national annexes (AFNOR 2008; 2012): NF EN NA'08 and NF EN NA'12 is identified in departments of Metropolitan France or overseas departments. However, it may be consulted in practice if required. For five overseas collectivities, on the other hand, compliance with any edition of NV 65s is required for wind-related risks in most municipalities of St. Martin in accordance with PPRN (SEBM 2019): MFPPRN'19. In French Polynesia, the government council orders (CG 1983a; b): PFCG'83, which require compliance with the Unified Technical Document (CSTB 1976): NV 65'76, are promulgated under the Planning Code (GPF 1961). In St. Pierre and Miquelon, EN'05 with NF EN NA'08 and NF EN NA'12, as well as the reference wind speed for alpine departments of Metropolitan France, has been consulted in practice. (Doligé et al. 2017) In the sui generis collectivity: New Caledonia, the governmental order (GNC 2020), which requires compliance with EN'05 with NF EN NA'08 and NF EN NA'12, is promulgated in accordance with the Congress deliberation (GNC 2016).

4) Germany

Either the 2017 or 2019 edition of the Model Administrative Regulations for Technical Building Regulations (DIBt 2017; 2019), which requires compliance with EN'05 with the national annex (DIN 2010): DIN EN NA'10, is enforced in all constituent states under respective acts. (DIBt 2018)

5) Liechtenstein

The Building Regulations (GLI 2009), which accept standards of the Swiss professional society and EU countries, are enforced under the *Building Act (BauG)* (2008). Of these, the Swiss professional society standards (SIA 2003; 2006; 2014): SIA 261-1'03, SIA D 0188'06 and SIA 261'14, or EN'05 with the Swiss national annex (SNV 2016): SN EN NA'16 may be consulted in practice.

6) Luxembourg

The official journal (ILNAS 2011), which endorses EU standards including EN'05 with the national annex (ILNAS 2011): LU EN NA'11 as one of the legislative and regulatory acts, is issued under the *Law on Official Journal* (2016).

7) Monaco

The *Environmental Code* (2017) requires some prevention measures against foreseeable storm risks. However, no relevant regulation is identified under the Code. NV 65s or EN'05 with NF EN NA'08 may be consulted in practice. (Bougis 1998; 2018)

8) Netherlands

The Construction and Living Environment Decree (RNL 2018) is supposed to supersede the Building Decree (RNL 2012) and its subordinate regulation (MBZK 2018) in the European Netherlands from the year 2024. Both of these decrees require compliance with EN'05 with the national annex (NEN 2011): NEN EN NA'11. In the special municipalities: Bonaire, St. Eustatius and Saba, the Building Decree (MWR 2014), which requires compliance with the BES-code (MBZK 2015): BESC'15, is enforced under the *BES Public Housing, Spatial Planning and Environmental Management Act* (2011). BESC'15, which was developed using examples from UBC'97, requires compliance with the national standard (NEN 2007): NEN 6702'07. BESC'15 also accepts EN'05 with the national annex: NEN EN NA'11. On the other hand, in three constituent states: Aruba, Curacao and St. Maarten, the Building and Housing Ordinances (AWG 2013a; GAN 2001; RSX 2010) and their subordinate decrees (AWG 2013b; GAN 2010; RSX 2013): BWB'35, which were enacted at the time of Netherlands Antilles, are still enforced. However, these decrees define only one common wind pressure on roofs. In Aruba, therefore, EN'05 with NEN EN NA'11 and the research report (Kamsteeg 1981): OWA'81 have been consulted in practice. (Kamsteeg 2018) In St. Maarten, UBC'97 and a reference wind speed based on wind speed records from past hurricanes may be consulted in practice. (Daal 2017)

9) Switzerland

The Building Regulations (KSO 2013a), which require compliance with professional society standards, are enforced in at least one of the 26 cantons: Solothurn under the Planning and Building Act (KSO 2013b). Therefore, compliance with the Regulations is established through the professional society standards for wind actions (SIA 2003; 2006; 2014): SIA 261-1'03, SIA D 0188'06, and SIA 261'14, or through EN'05 with the national annex (SNV 2016): SN EN NA'16, which is administered as one of the professional society standards. SN EN NA'16 serves as an index of relevant parts of SIA 261'14 and SIA D 0188'06.

2.2.5 Oceania

(1) Australia and New Zealand

1) Australia

The Building Code (ABCB 2019), which requires compliance with the Australian (AU) and New Zealand (NZ) joint standard (AS/NZS 2011): AS/NZS 1170.2'11, is enforced in all states and internal territories under their respective acts, ordinances, or regulations. (ABCB 2017) Furthermore, two external territories: Christmas Island and Cocos (Keeling) Islands fully follow the Building

Regulations for Western Australia (GWA 1989) based on the Local Government (Transition) Ordinances (AGD 1992a; b). In Norfolk Island, compliance with the Building Regulations (NFG 2004) is established through the withdrawn Building Code (ABCB 2003), which accepts the AU national standard (AS 1993): AS 1170.2'89 and the AU and NZ joint standard (AS/NZS 2002): AS/NZS 1170.2'02, under the *Building Act 2002* (2002).

2) New Zealand

The Building Code (GNZ 1992) is enforced under the *Building Act 2004* (2004). Compliance with the Code is established through the Acceptable Solutions and Verification Methods (MBIE 2021), which accept AS/NZS 1170.2'11. In one dependent territory: Tokelau, the Building Code (COGT 2008), which requires compliance with AS 1170.2'89, is enforced under the *Building Rules 2007* (2007). In addition, AS/NZS 1170.2'02 may be consulted in practice. (Spaak 2017) Of two associated states, in Cook Islands, the Building Code (ICI 2019): NBCCK'19, which requires compliance with AS/NZS 1170.2'11, is enforced under the *Building Controls and Standards Act 1991* (1991). In Niue, although the Building Code: NBCNU'20 is enforced under the *Building Code Amendment Act 2021* (MINU 2021), neither the Code nor the Act were accessible for this study. The previous edition (CNU 1990): NBCNU'90, which required compliance with AS 1170.2'89, had been enforced under the *Building Code Act 1992* (1992).

(2) Melanesia

1) Fiji

The National Building Code (MHFJ 2004): NBCFJ'04, which requires compliance with AS 1170.2'89, is enforced under the *Public Health Act* (1936). AS 1170.2'89 is also recognized as one of the national standards. (MITT 2010)

2) Papua New Guinea

The Building Regulations (GPG 1994), which require compliance with the national standard (PNGSC 1982): PNGS 1001.3'82, are enforced under the *Building Act 1971* (1971). The source of PNGS 1001.3'82 is the AU national standard (SAA 1981): AS 1170.2'81.

3) Solomon Islands

Even in the capital, Honiara, the Building Ordinance (HCC 1995) does not require buildings to withstand winds. The draft National Building Code (MIDSB 2022): NBCSB'22, which requires compliance with AS/NZS 1170.2s, may be consulted in practice. The Code is planned to be legislated under the *National Building Code Bill 2021* (2021), which is supposed to become the National Building Code Act. (Iroga 2021)

4) Vanuatu

The National Building Code (MIPU 2000): NBCVU'00, which requires compliance with AS 1170.2'89, is enforced under the *Building Act 2013* (2013).

(3) Micronesia

1) Federated States of Micronesia

The existing State Building Codes (CSG 1991; KSL 2013; PSG 1989; YSG 1997) do not define any structural safety requirements for buildings. IBC'18 has been consulted in practice. (DTCI 2016) Development of the IBC-based National Building Code is underway in accordance with the Infrastructure Development Plan (GFM 2015). (Clark 2021)

2) Kiribati

The National Building Code (MPWU 2012): NBCKI'12, which requires compliance with AS/NZS 1170.2'11, is enforced under the *Building Act 2006* (2006).

3) Marshall Islands

The National Building Code (ICC 2022): NBCMH'21 was developed using examples from IBC'18 under the *Planning and Zoning Act 1987* (1987). NBCMH'21 is supposed to be enshrined into law based on the rule-making procedure defined by the Act.

4) Nauru

The draft National Building Code (DID 2023): NBCNR'23, which requires compliance with AS/NZS 1170.2s, is supposed to be enforced under a yet-to-be-established Building Act.

5) Palau

The latest draft National Building Safety Standards, which were deliberated but not enacted by the National Congress (Reklai 2021), were not accessible for this study. The latest edition aims to avoid confusion caused by compliance with multiple US model codes, such as the US model code (ICBO 1988): UBC'88, IBC'12, and their subsequent editions, unlike the previous edition (PCC 2016): NBSS'16. (Reklai 2016)

(4) Polynesia

1) Samoa

The National Building Code (MWTI 1992): NBCWS'92, which requires compliance with the NZ national standard (SANZ 1984): NZS 4203'84, is enforced under the *Ministry of Works Act 2002* (2002). The source of NZS 4203'84 is BS CP3 CV2'72. The revised edition (MWTI 2017): NBCWS'17, which adopts AS/NZS 1170.2'11, is supposed to supersede the Code. (MWTI 2020)

2) Tonga

The National Building Code (MWTO 2007): NBCTO'07, which requires compliance with AS/NZS 1170.2'02, is enforced under the *Building Controls and Standards Act* (2016).

3) Tuvalu

No ministerial regulations prescribing a national building code are enforced under the *Building Act*

2019 (2019). The draft National Building Code (AIDAB 1990): NBCTV'90, which requires compliance with AS 1170.2'89, may be consulted in practice.

2.3 Conclusions

This chapter studied ongoing facts about legal and regulatory frameworks, as well as codes and standards for wind-resistant design of buildings in all 195 countries. First, we collected and analyzed a substantial amount of relevant information, considering three levels of jurisdictional areas and undergoing a process of trial and error. Then, we summarized the status of laws, regulations, codes, and standards for each country although there were some differences in the amount of information. The results are summarized as follows:

(1) Study policy

This chapter succeeded in covering all 195 countries, 193 of which are member states of the UN and two of which are observer states at the UN General Assembly, by:

- considering three levels of jurisdictional areas: countries (first level), states or provinces (second level), and cities (third level),
- conducting email interviews with consultants, researchers, or officials, if necessary, in addition to obtaining online information,
- fully utilizing Google Search and Translate to obtain and understand online information, and
- undergoing a process of trial and error in three phases: 1) obtaining relevant information from other countries, 2) correctly scanning the contents of the information, and 3) accurately understanding them.

(2) Legal and regulatory frameworks

This chapter also revealed the following findings.

- At least 137 countries, accounting for 70% of the total, have established legal and regulatory frameworks including provisions on wind-resistant design of buildings.
- At most 58 countries, accounting for 30% of the total, have not established legal and regulatory frameworks including provisions on wind-resistant design of buildings. Of these, African countries account for most of them.
- Developed countries do not always enact legislation for wind-resistant design of buildings (e.g., Belgium).
- Developing countries do not always establish legal and regulatory frameworks akin to those of closely related developed countries (e.g., Ukraine).
- Some countries incorporate provisions on wind-resistant design of buildings into regulations for seismic-resistant design of buildings (e.g., Cuba).

This chapter contributed to a specific objective of this thesis: summarizing worldwide information on legal and regulatory frameworks, including provisions on wind-resistant design of buildings, as well as codes and standards for wind-resistant design of buildings.

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3 WORLDWIDE STATUS ON LEGAL AND REGULATORY FRAMEWORKS

In this chapter, we discuss the worldwide status on legal and regulatory frameworks in 137 countries identified in Chapter 2, focusing on three types of provisions: wind-resistant design liability, wind load calculation methods, and reference wind speeds or pressures. First, we study the current worldwide status for each type of provision, and then analyze the status from two perspectives: jurisdictions and requirements. Next, we examine worldwide challenges in establishing legal and regulatory frameworks from three perspectives: human or economic damage from storms, and economic development of countries. Furthermore, we discuss the future status of legal and regulatory frameworks based on national or subnational initiatives in the remaining 58 countries that currently lack them.

Relevant journal paper:

- Hayakawa, A., Matsui, M., and Tamura, Y. 2022. “Worldwide Status on Legal and Regulatory Frameworks with Provisions Related to Wind-resistant Design of Buildings.” *Journal of Wind Engineering, JAWE*, 47(2(171)), 5(1)-17(13).

3.1 Provisions on Wind-resistant Design of Buildings

Provisions related to wind-resistant design of buildings mentioned within the legal and regulatory frameworks of the 137 countries are mostly divided into three types of provisions: 1) wind-resistant design liability, 2) wind load calculation methods, and 3) reference wind speeds or pressures. They are defined in this thesis as follows.

3.1.1 Three types of provisions

(1) Wind-resistant design liability

Wind-resistant design liability is mentioned or implied through four types of clauses that require:

- specific wind load calculation methods, as well as specific wind speeds, velocity pressures or wind pressures,
- consideration of the most unfavorable conditions due to earthquakes or winds,
- structural safety against strong winds, climatic extremes, hurricanes, or storm risks, and
- compliance with codes or standards from specific countries rather than specific codes or standards.

The first type of clause includes the provision that simply cites an existing nationally or internationally recognized code or standard. The second type includes the provision that does not clearly define wind load calculation methods, as well as reference wind speeds, velocity pressures or wind pressures. The third type includes the provision that implicitly requires buildings to withstand strong winds. The fourth type includes the provision that follows other countries imposing wind-resistant design liability.

(2) Wind load calculation methods

Wind load calculations are the most critical process for ensuring wind-resistant design of structures. The methods were developed for structural design of buildings, bridges, towers, cladding, or cables, etc. Of these, this study covered all the procedures for calculating design wind loads on building structures, components, or claddings, excluding specialized procedures for bridge structures, or power or telecommunications facilities. However, it was set as a condition that they could estimate at least either alongwind loads or roof wind loads although they were differences in technical approaches.

(3) Reference wind speeds or pressures

Reference wind speeds or pressures are particularly important country- or site-specific values that underlie the setting of design wind loads. They are defined by any of the following three criteria:

- wind speed,
- velocity pressure, or
- wind pressure.

Most of the reference wind speeds or pressures are defined as the wind speed or velocity pressure averaged over any period, referenced to any height over any terrain roughness, for any probability of exceedance in one year, with the effects of site-specific conditions such as topographic and orographic effects removed. At the same time, some of them are defined as the wind speed or velocity pressure with

any of the averaging time, reference height, terrain roughness, or return period undefined and without the effects of site-specific conditions removed. However, both are commonly provided by a map with isopleth lines or zoning, or a list organized by administrative jurisdictions or for large cities. On the other hand, a few of them are defined as the wind pressure simplified to the safe side by incorporating building-specific conditions such as wind force or pressure coefficients together with site-specific conditions. They are commonly simplified as a step function of height or a constant value regardless of height, without considering the concepts of averaging time, terrain roughness, or return period.

3.1.2 Worldwide status

Table 3.1 organizes the establishment status of three types of provisions in 195 countries. Check marks: “✓” show that each provision has been enacted. Hyphens: “-” mean that laws or regulations related to wind-resistant design of buildings were not identified in this study. However, it does not always mean that they do not exist. Suffixes: “s” and “m” attached to the check mark signify that each provision is legislated at subnational levels and accepts multiple systems, respectively. Countries with an asterisk: “*” after their names have established a federal governmental system. Administrative rules, which are orders within an administrative agency and apply to public building construction activities, are not considered even if they stipulate any of these provisions. As shown in this table, when reference wind speeds or pressures are defined within the legal and regulatory framework, wind load calculation methods are also stipulated therein. Furthermore, when wind load calculation methods are stipulated within the legal and regulatory framework, wind-resistant design liability is also mentioned therein. There is no converse, unsurprisingly.

Table 3.2 shows the breakdown of 137 countries with three types of provisions. The numerical values in parentheses: () and [] show the total number of countries that lie within each region or subregion and the percentage of the 195 countries, respectively. This table shows that all 137 countries covered in this chapter, accounting for 70% of the total, mention or imply wind-resistant design liability. Of these, 121 and 115 countries, accounting for 62% and 59% of the total, establish provisions regarding wind load calculation methods and reference wind speeds or pressures, respectively.

Figure 3.1 shows Table 3.2 on the world map. Here, countries colored green, orange, and yellow represent those that require all three types of provisions, two types of provisions: wind-resistant design liability and wind load calculation methods, and only one type of provision: wind-resistant design liability, respectively. Hyphens: “-” are synonymous with those in Table 3.1. Additionally, this figure individually shows the status of 30 small countries with less than 5,000 km². This figure shows that the countries colored green are widely found in the Americas, Asia, Europe and Oceania. In addition, it shows that the countries colored orange are found in only Africa and Asia, as well as the countries colored yellow are found in Africa, the Americas, Asia, and Europe.

Table 3.1 List of the establishment status of three types of provisions in 195 countries

Country	Wind-resistant design liability	Wind load calculation methods	Reference wind speeds or pressures	Country	Wind-resistant design liability	Wind load calculation methods	Reference wind speeds or pressures
Africa				Sierra Leone	-	-	-
Eastern Africa				Togo	-	-	-
Burundi	-	-	-	Americas			
Comoros*	-	-	-	Caribbean			
Djibouti	-	-	-	Antigua and Barbuda	✓	✓	✓
Eritrea	-	-	-	Bahamas	✓	✓	✓
Ethiopia*	✓	✓	✓	Barbados	-	-	-
Kenya	-	-	-	Cuba	✓	-	-
Madagascar	✓	✓	✓	Dominica	✓	-	-
Malawi	✓ s	-	-	Dominican Republic	-	-	-
Mauritius	-	-	-	Grenada	✓	✓ m	✓ m
Mozambique	✓	✓	✓	Haiti	-	-	-
Rwanda	✓	✓	✓	Jamaica	✓	✓	✓
Seychelles	✓	✓	✓	St. Kitts and Nevis*	✓	✓	✓
Somalia*	-	-	-	St. Lucia	-	-	-
South Sudan*	-	-	-	St. Vincent and the Grenadines	✓	✓	✓
Tanzania	✓	✓	✓	Trinidad and Tobago	-	-	-
Uganda	✓	✓	✓	Central America			
Zambia	-	-	-	Belize	✓	-	-
Zimbabwe	✓ s	✓ s	✓ s	Costa Rica	✓	✓	✓
Middle Africa				El Salvador	✓	✓	✓
Angola	✓	-	-	Guatemala	✓	✓	✓
Cameroon	-	-	-	Honduras	✓	✓	✓
Central African Republic	-	-	-	Mexico*	✓ s	✓ s	✓ s
Chad	-	-	-	Nicaragua	✓	✓	✓
Congo-Brazzaville	-	-	-	Panama	✓	✓	✓
Congo-Kinshasa	-	-	-	Northern America			
Equatorial Guinea	-	-	-	Canada*	✓ s	✓ s	✓ s
Gabon	-	-	-	United States*	✓ s	✓ s	✓ s
Sao Tome and Principe	-	-	-	South America			
Northern Africa				Argentina*	✓	✓	✓
Algeria	✓	✓	✓	Bolivia	✓ s	✓ s	✓ s
Egypt	✓	✓	✓	Brazil*	✓ s	✓ s	✓ s
Libya	-	-	-	Chile	✓	✓	✓
Morocco	✓	-	-	Colombia	✓	✓	✓
Sudan*	-	-	-	Ecuador	✓	✓	✓
Tunisia	-	-	-	Guyana	-	-	-
Southern Africa				Paraguay	✓ s	✓ s	✓ s
Botswana	✓	✓ m	-	Peru	✓	✓	✓
Eswatini	✓	✓	-	Suriname	✓	✓	✓
Lesotho	✓	-	-	Uruguay	-	-	-
Namibia	✓	✓	✓	Venezuela*	✓	✓	✓
South Africa	✓	✓	✓	Asia			
Western Africa				Central Asia			
Benin	-	-	-	Kazakhstan	✓	✓	✓
Burkina Faso	-	-	-	Kyrgyzstan	✓	✓	✓
Cabo Verde	✓	✓ m	-	Tajikistan	✓	✓	✓
Ivory Coast	✓	-	-	Turkmenistan	✓	✓	✓
Gambia	-	-	-	Uzbekistan	✓	✓	✓
Ghana	✓	✓	✓	Eastern Asia			
Guinea-Bissau	-	-	-	China	✓ s	✓ s	✓ s
Guinea-Conakry	-	-	-	Japan	✓	✓	✓
Liberia	-	-	-	Mongolia	✓	✓	✓
Mali	-	-	-	North Korea	-	-	-
Mauritania	✓	-	-	s : Provisions that are defined at subnational levels m : Provisions that accept multiple systems * : Country that establishes the federal governing system			
Niger	-	-	-				
Nigeria*	✓ s	✓ s	-				
Senegal	✓	-	-				

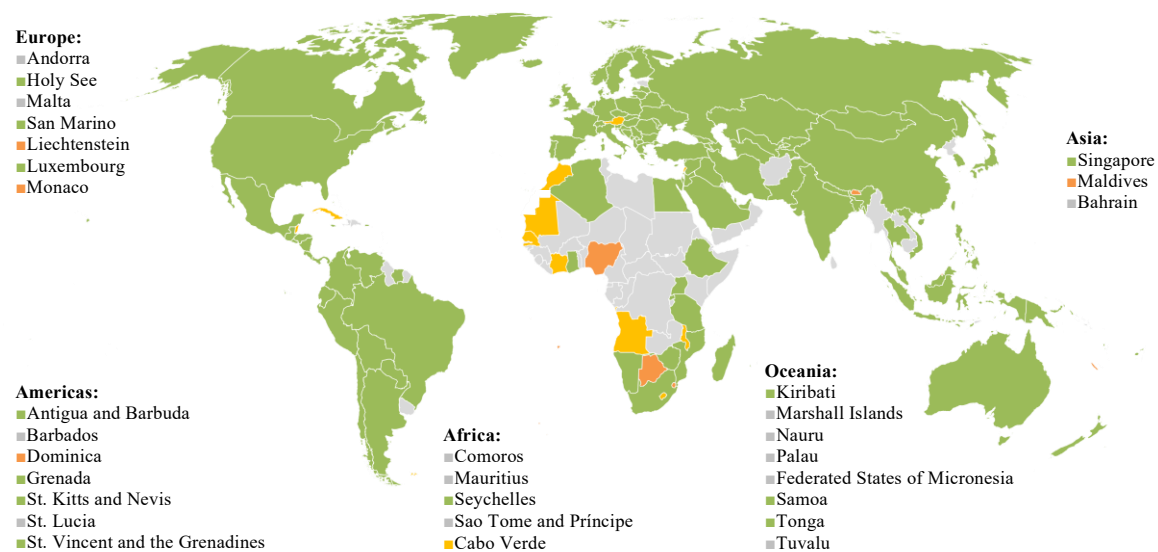
Table 3.1 List of the establishment status of three types of provisions in 195 countries (cont'd)

Country	Wind-resistant design liability	Wind load calculation methods	Reference wind speeds or pressures	Country	Wind-resistant design liability	Wind load calculation methods	Reference wind speeds or pressures
South Korea	✓	✓	✓	Finland	✓ s	✓ s	✓ s
South-eastern Asia				Iceland	✓	✓	✓
Brunei	✓	✓ m	-	Ireland	✓	✓	✓
Cambodia	-	-	-	Latvia	✓	✓	✓
Indonesia	✓	✓	✓	Lithuania	✓	✓	✓
Laos	-	-	-	Norway	✓	✓	✓
Malaysia*	✓ s	✓ s	✓ s	Sweden	✓	✓	✓
Myanmar	-	-	-	United Kingdom	✓ s	✓ s	✓ s
Philippines	✓	✓	✓	Southern Europe			
Singapore	✓	✓ m	✓ m	Albania	✓	✓	✓
Thailand	✓	✓	✓	Andorra	-	-	-
Timor-Leste	-	-	-	Bosnia and Herzegovina*	✓ s	✓ s,m	✓ s
Vietnam	✓	✓	✓	Croatia	✓	✓	✓
Southern Asia				Greece	✓	✓ m	✓ m
Afghanistan	-	-	-	Holy See	✓	✓	✓
Bangladesh	✓	✓	✓	Italy	✓	✓	✓
Bhutan	✓	✓	-	Malta	-	-	-
India*	✓ s	✓ s	✓ s	Montenegro	✓	✓ m	✓ m
Iran	✓	✓	✓	North Macedonia	✓	✓ m	✓ m
Maldives	✓	-	-	Portugal	✓	✓ m	✓ m
Nepal*	✓	✓	✓	San Marino	✓	✓	✓
Pakistan*	✓ s	✓ s,m	✓ s	Serbia	✓	✓	✓
Sri Lanka	-	-	-	Slovenia	✓	✓	✓
Western Asia				Spain	✓	✓	✓
Armenia	✓	✓	✓	Western Europe			
Azerbaijan	✓	✓	✓	Austria*	✓ s	-	-
Bahrain	-	-	-	Belgium*	-	-	-
Cyprus	✓	✓	✓	France	✓ s	✓ s	✓ s
Georgia	✓	✓	✓	Germany*	✓ s	✓ s	✓ s
Iraq*	✓	✓	✓	Liechtenstein	✓	-	-
Israel	✓	✓	✓	Luxembourg	✓	✓	✓
Jordan	✓	✓	✓	Monaco	✓	-	-
Kuwait	-	-	-	Netherlands	✓ s	✓ s,m	✓ s
Lebanon	✓	-	-	Switzerland*	✓ s	✓ s	✓ s
Oman	-	-	-	Oceania			
Palestine	✓ s	-	-	Australia and New Zealand			
Qatar	✓	✓ m	✓ m	Australia*	✓ s	✓ s	✓ s
Saudi Arabia	✓	✓	✓	New Zealand	✓ s	✓ s	✓ s
Syria	✓ s	✓ s	✓ s	Melanesia			
Turkey	✓	✓ m	✓ m	Fiji	✓	✓	✓
United Arab Emirates*	✓ s	✓ s,m	✓ s	Papua New Guinea	✓	✓	✓
Yemen	-	-	-	Solomon Islands	-	-	-
Europe				Vanuatu	✓	✓	✓
Eastern Europe				Micronesia			
Belarus	✓	✓	✓	Federated States of Micronesia*	-	-	-
Bulgaria	✓	✓ m	✓ m	Kiribati	✓	✓	✓
Czech	✓	✓	✓	Marshall Islands	-	-	-
Hungary	✓	✓	✓	Nauru	-	-	-
Moldova	✓	✓	✓	Palau	-	-	-
Poland	✓	✓	✓	Polynesia			
Romania	✓	✓	✓	Samoa	✓	✓	✓
Russia*	✓	✓	✓	Tonga	✓	✓	✓
Slovakia	✓	✓	✓	Tuvalu	-	-	-
Ukraine	✓	✓	✓	s : Provisions that are defined at subnational levels m : Provisions that accept multiple systems * : Country that establishes the federal governing system			
Northern Europe				Denmark	✓ s	✓ s	✓ s
Estonia	-	-	-				

Table 3.2 Breakdown of 137 countries with three types of provisions

Region	Subregion	Wind-resistant design liability	Wind load calculation methods	Reference wind speeds or pressures
Africa (54)	Eastern Africa (18)	9	8	8
	Middle Africa (9)	1	0	0
	Northern Africa (6)	3	2	2
	Southern Africa (5)	5	4	2
	Western Africa (16)	6	3	1
	Subtotal	24	17	13
Americas (35)	Caribbean (13)	8	6	6
	Central America (8)	8	7	7
	Northern America (2)	2	2	2
	South America (12)	10	10	10
	Subtotal	28	25	25
Asia (48)	Central Asia (5)	5	5	5
	Eastern Asia (5)	4	4	4
	South-eastern Asia (11)	7	7	6
	Southern Asia (9)	7	6	5
	Western Asia (18)	14	12	12
	Subtotal	37	34	32
Europe (44)	Eastern Europe (10)	10	10	10
	Northern Europe (10)	9	9	9
	Southern Europe (15)	13	13	13
	Western Europe (9)	8	5	5
	Subtotal	40	37	37
Oceania (14)	Australia and New Zealand (2)	2	2	2
	Melanesia (4)	3	3	3
	Micronesia (5)	1	1	1
	Polynesia (3)	2	2	2
	Subtotal	8	8	8
Total (195)		137 [70]	121[62]	115 [59]

Note: the numerical values in parentheses: () and [] show the total number of countries that lie within each region and subregion and the percentage of the 195 countries, respectively.



Color	Wind-resistant design liability	Wind load calculation methods	Reference wind speeds or pressures
■	✓	✓	✓
■	✓	✓	-
■	✓	-	-

Figure 3.1 Distribution of three types of provisions in 137 countries

3.2 Legal and Regulatory Jurisdiction

In many countries, the law that requires structural safety of buildings and concurrently confers the power to make regulations to the central government or local governments is enacted by the legislature, which is the sole legislative organ of the country. In this case, to achieve structural safety of buildings, wind-resistant design liability is mentioned in the law, and wind load calculation methods and reference wind speeds or pressures are provided in the regulations made by responsible administrative agencies under the central government or local governments. Most of them are provided through either or both of two types of regulations that require:

- one's own code or standard developed based on existing codes or standards, and
- existing codes or standards without any change.

The first type of regulations means that the responsible administrative agency makes regulations that define wind load calculation methods with nationally or internationally recognized codes or standards, simplified or combined, together with reference wind speeds or pressures. In addition, the regulations, in which existing wind load calculation methods or reference wind speeds or pressures were revised, are also included in this type. Even if existing codes or standards are partially accepted without any change in the regulations, the scope of applications are clearly distinguished from developed parts. On the other hand, the second type means that the responsible administrative agency makes regulations only to list nationally or internationally recognized codes or standards that define wind load calculation methods or reference wind speeds or pressures. If internationally recognized codes or standards are listed as methods for calculating wind loads in the regulations, reference wind speeds or pressures are generally defined, taking into account the climatic conditions of the respective countries. Unlike the first type, the second type, which is often seen in emerging countries, is not always properly adjusted to the educational or technical levels of the respective countries, nor is it aligned with the regulations against other natural disasters such as earthquake disasters.

Table 3.3 shows the breakdown of 137 countries with three types of provisions by national or subnational legislation. Figure 3.2 to Figure 3.4 show this table on the world map. The table and figures cover 137 countries mentioning or implying wind-resistant design liability, as well as 121 and 115 countries defining wind load calculation methods and reference wind speeds or pressures, respectively. Here, national and subnational legislation are defined as legislation conducted by the central government and local governments, respectively. National legislation was also considered when both national and subnational legislation were identified in the same country. The countries colored green and orange in these figures represent those with national and subnational legislation, respectively. Additionally, these figures individually show the status of 30 small countries with less than 5,000 km². The table and figures demonstrate that countries establishing these provisions at the national level constitute a majority in the countries with each legislation. Their numbers are 110, 97, and 92, accounting for 56%, 50%, and 47% of the total, respectively. Meanwhile, the numbers of countries establishing these provisions at subnational levels are 27, 24, and 23, accounting for 14%, 12%, and 12% of the total, respectively. They commonly cover approximately 20% of the countries with each legislation.

It is natural that the legal and regulatory framework is influenced by the governmental system of each country. The governmental system is categorized into either a unitary or a federal governmental system. A unitary governmental system is one in which a country is governed as a single entity by a central government, while a federal governmental system is one in which a country is governed as a political entity characterized by a union of partially self-governing states or provinces under a central federal government. Of the 195 countries, 168 and 27 have unitary and federal governmental systems, respectively.

In many cases, national and subnational legislation correspond to legislation under unitary and federal governmental systems, respectively. However, there are some exceptions. National legislation is not established in 13 countries with unitary governmental systems, which add seven countries with overseas territories: China, Denmark, Finland, the United Kingdom, France, the Netherlands, and New Zealand to six countries: Malawi, Zimbabwe, Bolivia, Paraguay, Palestine, and Syria. This largely originates from historical or geographical backgrounds. Meanwhile, national legislation with higher enforcement is established in seven countries with federal governmental systems: Ethiopia, St. Kitts and Nevis, Argentina, Venezuela, Nepal, Iraq, and Russia.

Table 3.3 Breakdown of 137 countries with three types of provisions by national or subnational legislation

Region	Wind-resistant design liability		Wind load calculation methods		Reference wind speeds or pressures	
	National legislation	Subnational legislation	National legislation	Subnational legislation	National legislation	Subnational legislation
Africa	21	3	15	2	12	1
Americas	22	6	19	6	19	6
Asia	30	7	28	6	26	6
Europe	31	9	29	8	29	8
Oceania	6	2	6	2	6	2
Total	110 [56]	27 [14]	97 [50]	24 [12]	92 [47]	23 [12]

Note: the numerical value in parentheses: [] shows the percentage of the 195 countries.

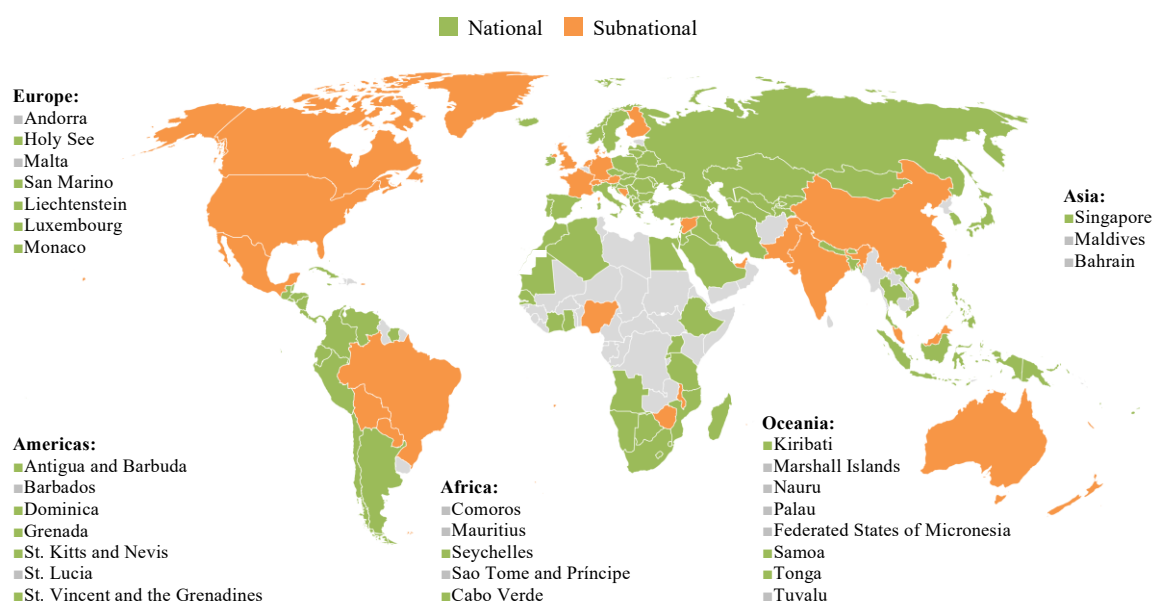


Figure 3.2 Distribution of national or subnational legislation in 137 countries mentioning or implying wind-resistant design liability

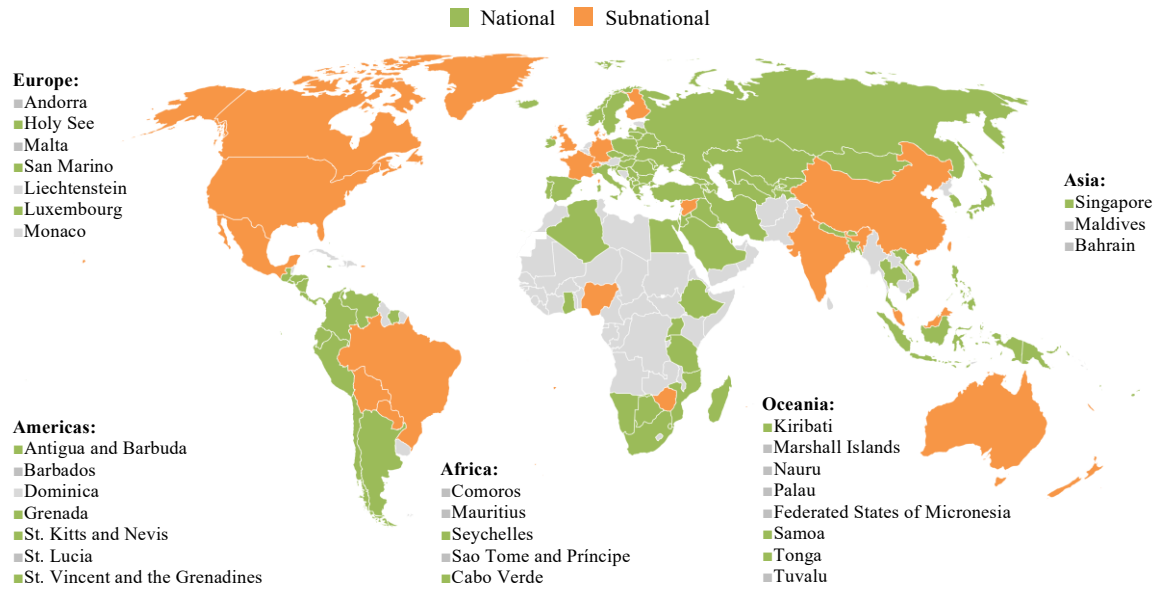


Figure 3.3 Distribution of national or subnational legislation in 121 countries defining wind load calculation methods

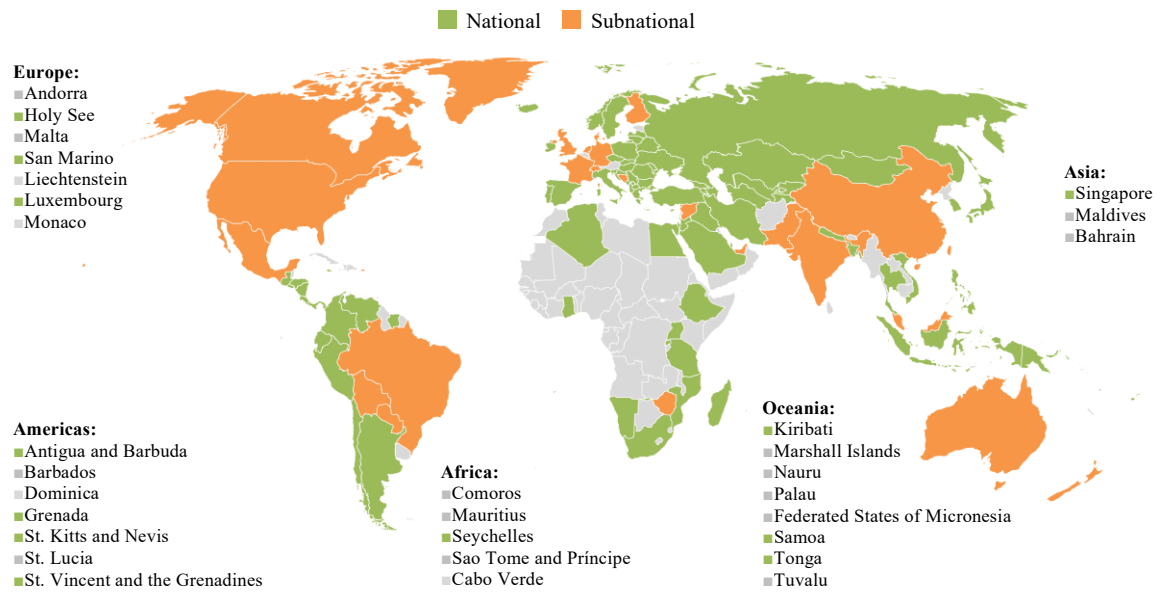


Figure 3.4 Distribution of national or subnational legislation in 115 countries defining reference wind speeds or pressures

3.3 Legal and Regulatory Requirements

Provisions related to wind-resistant design of buildings are also characterized by dividing the three types of provisions into two groups: 1) wind-resistant design liability and 2) wind load calculation methods or reference wind speeds or pressures.

3.3.1 Wind-resistant design liability

Some countries do not explicitly define any wind load calculation methods or reference wind speeds or pressures, although wind-resistant design liability is mentioned or implied within the legal and regulatory framework. Sixteen countries that place the check mark in only the field of wind-resistant design liability of Table 3.1 fall into this category. These countries correspond to those that mention wind-resistant design liability through the aforementioned second to fourth clauses that require:

- the most unfavorable conditions due to earthquakes or winds to be taken into consideration,
- structural safety to be ensured against strong winds, climatic extremes, hurricanes, or storm risks, and
- codes or standards from specific countries to be followed rather than specific codes or standards.

The first and second group of countries do not define any specific wind load calculation methods or reference wind speeds or pressures. Two countries: Morocco and Cuba and twelve countries: Malawi, Angola, Lesotho, Ivory Coast, Mauritania, Senegal, Dominica, Belize, Maldives, Palestine, Austria, and Monaco were classified into the first and second groups, respectively. The third group does not even imply the importance of wind-resistant design of buildings. Two countries: Lebanon and Liechtenstein belong to this group.

Table 3.4 shows the breakdown of 16 countries mentioning or implying only wind-resistant design liability by national or subnational legislation. Figure 3.5 shows this table on the world map. Here, the countries colored green and orange represent those with national and subnational legislation, respectively. Also, this figure shows the status of four small countries with less than 5,000 km². Thirteen and three countries require wind-resistant design liability at the national and subnational levels, respectively. Of these, the three countries are Malawi, Palestine, and Austria.

Table 3.4 Breakdown of 17 countries mentioning or implying only wind-resistant design liability

Region	National legislation	Subnational legislation	Total
Africa	6	1	7
Americas	3	0	3
Asia	2	1	3
Europe	2	1	3
Oceania	0	0	0
Total	13 [6.7]	3 [1.5]	16 [8.2]

Note: the numerical value in parentheses: [] shows the percentage of the 195 countries.

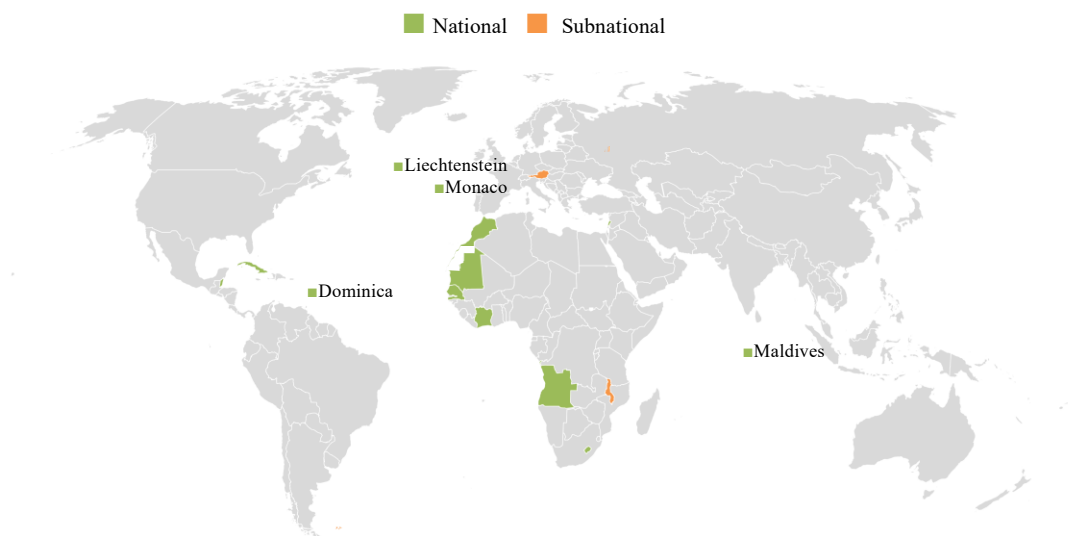


Figure 3.5 Distribution of national or subnational legislation in 16 countries mentioning or implying only wind-resistant design liability

3.3.2 Wind load calculation methods or reference wind speeds or pressures

Some countries accept multiple systems in either wind load calculation methods or reference wind speeds or pressures within the legal and regulatory framework. Sixteen and nine countries with the check mark with the suffix “m” in the fields of wind load calculation methods and reference wind speeds or pressures of Table 3.1, respectively, fall into this category. Most of them accept one of the two systems that adopt:

- any of two or more internationally recognized wind load calculation methods or reference wind speeds or pressures, or
- any of their own rather old or other country-developed internationally recognized wind load calculation methods or reference wind speeds or pressures.

The former is because their own wind load calculation methods or reference wind speeds or pressures have not been developed. The latter is because their own wind load calculation methods or reference wind speeds or pressures have not been updated. At any rate, these countries are in the transition phase from old to new wind load calculation methods or reference wind speeds or pressures pursuant to national or subnational policies or plans, as well as multilateral agreements.

Table 3.5 shows the breakdown of 16 countries defining multiple wind load calculation methods and nine countries defining multiple reference wind speeds or pressures by national or subnational legislation. Figure 3.6 and Figure 3.7 show this table on the world map. Here, the countries colored green, and orange represent those with national and subnational legislation, respectively. Also, these figures show the status of three small countries with less than 5,000 km². However, this table excluded countries that adopt:

- one system of wind load calculation methods or reference wind speeds or pressures within each jurisdiction, and
- two or more almost the same systems of wind load calculation methods or reference wind speeds or pressures within each jurisdiction.

The former includes seven countries: Mexico, China, Malaysia, Denmark, the United Kingdom, France, and New Zealand, which have multiple systems at the national level but adopt only one system at the state or provincial level, including overseas territories, as shown in Chapter 2. The latter includes seven countries: Canada, the United States, India, and Australia, which accept both previous editions and the current edition with new findings in addition to previous editions; Ghana, which accepts both BS CP3 CV2’70 and the national standard developed using examples from BS CP3 CV2’70; Bolivia, which accepts both the municipal and national standards developed using examples from CIRSOC 102’05; and Switzerland, which publishes the national annex for the European Union standard serving as an index of relevant parts of the current professional society standards, as shown in Chapter 2.

The tables and figures reveal that 12 countries: Botswana, Cabo Verde, Grenada, Brunei, Singapore, Qatar, Turkey, Bulgaria, Greece, Montenegro, North Macedonia, and Portugal accept multiple wind load calculation methods at the national level. Of these, three countries: Botswana, Cabo Verde, and Brunei do not define any reference wind speeds or pressures. However, they also reveal that four countries: Pakistan, the United Arab Emirates, Bosnia and Herzegovina, and the Netherlands accept multiple wind load calculation methods at subnational levels. Of these, two countries: the United Arab Emirates (Dubai) and

the Netherlands (Bonaire, St. Eustatius and Saba) define only one common reference wind speed or pressure for multiple systems, and the remaining two countries: Pakistan and Bosnia and Herzegovina define one or more reference wind speeds or pressures for only one specific system.

Table 3.5 Breakdown of 16 countries defining multiple wind load calculation methods or nine countries defining multiple reference wind speeds or pressures

Region	Wind load calculation methods			Reference wind speeds or pressures		
	National legislation	Subnational legislation	Total	National legislation	Subnational legislation	Total
Africa	2	0	2	0	0	0
Americas	1	0	1	1	0	1
Asia	4	2	6	3	0	3
Europe	5	2	7	5	0	5
Oceania	0	0	0	0	0	0
Total	12 [6.2]	4 [2.1]	16 [8.2]	9 [4.6]	0 [0.0]	9 [4.6]

Note: the numerical value in parentheses: [] shows the percentage of the 195 countries



Figure 3.6 Distribution of national or subnational legislation in 16 countries defining multiple wind load calculation methods

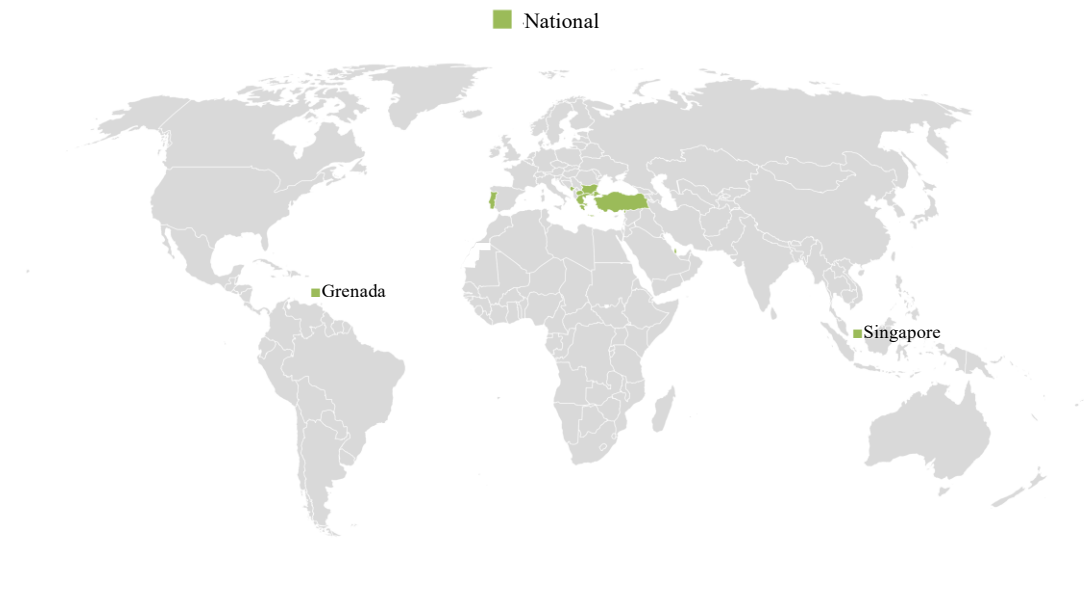


Figure 3.7 Distribution of national or subnational legislation in nine countries defining multiple reference wind speeds or pressures

3.4 Human or Economic Damage from Storms and Economic Development of Countries

Human or economic damage from storms and economic developments of countries are assumed to be significant factors in establishing laws or regulations related to wind-resistant design of buildings. Therefore, the relationships with legal and regulatory jurisdictions or requirements, as well as overall trends, are discussed from these three standpoints.

3.4.1 Human damage from storms

Table 3.6 organizes maximum human damage from storms in 195 countries. All damage and human losses over the last 50 years from 1971 to 2020 are considered based on the international disasters database (CRED 2009): EM-DAT. They include the number of people whose whereabouts since storm disasters are unknown or presumed dead based on official figures, as well as the number of people who lost their lives because storm events happened. The disaster classification used in EM-DAT is based on the Peril Classification and Hazard Glossary (IRDR 2014). Storms here include four types of storms in meteorological hazard: convective storms (Cs), extra-tropical storms (Es), tropical cyclones (Tc), and unclassifiable storms (Us). Table 3.7 shows their definitions. This table suggests that all damage and human losses due to storm disasters in EM-DAT are not always limited to wind-related disasters. Asterisks: “*” and hyphens “-” in Table 3.6 denote that countries establish federal governmental systems, and that EM-DAT has not recorded any storm events that resulted in human losses, respectively. According to Table 3.6, the largest human loss was 138,866 people recorded in Bangladesh in 1991. This is followed by Myanmar, which lost 138,366 people in 2008. Both countries are in tropical cyclone areas. Meanwhile, the largest human losses due to convective storms, extra-tropical storms, and unclassifiable storms were 139 people in North Macedonia in 2005, 117 people in Czech in 2007, and 139 people in Lesotho in 2001, respectively.

Table 3.6 also shows the level of maximum human damage from storms. Table 3.8 shows the classification thereof. Here, human losses are classified into four levels: no loss (0 people), small loss (1 to 13 people), medium loss (14 to 60 people) and large loss (more than 60 people). Of these, the last three levels were set to be almost the same number of countries for easy comparison. Table 3.9 shows the breakdown of 195 countries for each level of maximum human damage from storms. Figure 3.8 shows this table on the world map. Here, the countries colored green, blue, yellow, and red represent those with no loss, small loss, medium loss, and large loss, respectively. Also, this figure individually shows the status of 30 small countries with less than 5,000 km². The table and figure reveal that no or small loss areas spread across Africa and Europe, as well as large loss areas extend to the Americas and Asia with tropical cyclone areas.

(1) Overall trends

Figure 3.9 shows the breakdown of 195 countries on the legislation status for each country classification according to the level of maximum human damage per storm disaster. Parts colored dark and light red represent countries with and without any laws or regulations, respectively. As expected, this

figure shows that the number of countries that enforce laws or regulations increases with the rise of human damage level. 54 (=24+30) countries, which have not experienced any significant human damage from storms, are classified into no loss. Of these, 30 countries, accounting for 15% of the total countries, enforce laws or regulations. On the other hand, 48 (=14+34), 46 (=11+35), and 47 (=9+38) countries, which have experienced significant human damage from storms, are classified into small, medium, and large losses, respectively. Of these, 34 (=14+11+9) countries, accounting for 17% of the total, do not enforce any laws or regulations, although the number slightly decreases with the rise of human damage level.

Figure 3.10 shows Figure 3.9 on the world map. The countries colored red, yellow, blue, and green represent large, medium, small, and no losses, respectively. The dark and light colored countries represent those with and without any laws or regulations, respectively, as in Figure 3.9. Also, this figure individually shows the status of 30 small countries with less than 5,000 km². This figure shows that nine countries: Somalia, Dominican Republic, Haiti, North Korea, Myanmar, Afghanistan, Sri Lanka, Oman, and Solomon Islands have suffered a large loss, as well as eleven countries: Comoros, Kenya, Chad, Congo-Kinshasa, Sudan, Sierra Leone, Saint Lucia, Cambodia, Laos, Yemen, and the Federated States of Micronesia have suffered a medium loss. However, they have not established any laws or regulations. Most of these countries are recognized as least developed countries (LDCs) (OECD 2021). These facts suggest that the level of maximum human damage from storms is not always a decisive factor, but it does have some influence on the establishment of laws or regulations related to wind-resistant design of buildings.

(2) Trends in legal and regulatory jurisdictions or requirements

Figure 3.11 shows the breakdown of 137 countries establishing national or subnational legislation, defining one to three types of provisions, or accepting single or multiple systems for each country classification according to the level of maximum human damage per storm disaster. The upper diagram shows the number of countries that enforce laws or regulations at the national or subnational levels (two reds, dark and light). The middle diagram shows the number of countries that define all three types of provisions, two types of provisions: wind-resistant design liability and wind load calculation methods, and only one type of provision: wind-resistant design liability (three reds from dark to light). The lower diagram shows the number of countries that accept single or multiple systems in either wind load calculation methods or reference wind speeds or pressures (two reds, light and dark).

This figure reveals some relationships between the number of countries and the level of maximum human damage. The upper diagram shows that most countries have established laws or regulations at the national level, and the number is approximately the same number of countries regardless of human damage level. Also, the number of countries that have established laws or regulations at subnational levels increases with the rise of human damage level. The middle diagram shows that most countries define three types of provisions regardless of human damage level, and the number roughly trends to increase with the rise of human damage level. The lower diagram shows that only a few countries accept multiple systems regardless of human damage level, and the number roughly trends to decrease with the rise of human damage level.

Figure 3.12 to Figure 3.14 show the upper to lower diagrams in Figure 3.11 on the world map. The countries colored red, yellow, blue, and green represent large, medium, small and no losses, respectively.

The dark to light colored countries show the same as the contents shown in Figure 3.11. Also, these figures individually show the status of 30 small countries with less than 5,000 km². These figures reveal some facts. For example, Figure 3.12 and Figure 3.13 show that 10 countries: Zimbabwe, Mexico, the United States, China, Malaysia, India, Pakistan, France, Germany, and Australia, which are classified as large loss, have subnational legislation with three types of provisions. Moreover, Figure 3.14 shows that only one country: Pakistan, which is classified as large loss, has enforced multiple systems with three types of provisions at subnational levels. On the other hand, 24 countries: Madagascar, Mozambique, South Africa, El Salvador, Guatemala, Honduras, Nicaragua, Panama, Argentina, Chile, Peru, Venezuela, Kazakhstan, Japan, South Korea, Indonesia, the Philippines, Thailand, Vietnam, Bangladesh, Iran, Nepal, Russia, and Papua New Guinea, which are classified as large loss, have the national legislation with three types of provisions. However, all these countries have accepted only a single system under their respective jurisdictions.

Table 3.6 List of maximum human damage from storms in 195 countries from 1971 to 2020

Country	Year	Storm type	Maximum loss		Country	Year	Storm type	Maximum loss	
			Quantity	Level				Quantity	Level
Africa					Sierra Leone	1984	Us	60	medium
Eastern Africa					Togo	-	-	-	no
Burundi	2011	Cs	12	small	Americas				
Comoros*	1983	Tc	33	medium	Caribbean				
Djibouti	2018	Tc	2	small	Antigua and Barbuda	1998	Tc	2	small
Eritrea	1993	Cs	3	small	Bahamas	2019	Tc	356	large
Ethiopia*	-	-	-	no	Barbados	2017	Tc	1	small
Kenya	1988	Cs	50	medium	Cuba	1982	Tc	24	medium
Madagascar	2004	Tc	363	large	Dominica	2017	Tc	64	large
Malawi	2005	Us	11	small	Dominican Republic	1979	Tc	1,400	large
Mauritius	1975	Tc	9	small	Grenada	2004	Tc	39	medium
Mozambique	2019	Tc	603	large	Haiti	2004	Tc	2,754	large
Rwanda	2017	Cs	3	small	Jamaica	1988	Tc	49	medium
Seychelles	-	-	-	no	St. Kitts and Nevis*	1998	Tc	5	small
Somalia*	2013	Tc	162	large	St. Lucia	2010	Tc	14	medium
South Sudan*	-	-	-	no	St. Vincent and the Grenadines	2002	Tc	4	small
Tanzania	2015	Cs	47	medium	Trinidad and Tobago	1974	Tc	2	small
Uganda	2011	Cs	23	medium	Central America				
Zambia	-	-	-	no	Belize	2001	Tc	30	medium
Zimbabwe	2019	Tc	628	large	Costa Rica	1996	Tc	51	medium
Middle Africa					El Salvador	1998	Tc	475	large
Angola	-	-	-	no	Guatemala	2005	Tc	1,513	large
Cameroon	-	-	-	no	Honduras	1998	Tc	14,600	large
Central African Republic	2009	Cs	3	small	Mexico*	1976	Tc	600	large
Chad	2007	Us	14	medium	Nicaragua	1998	Tc	3,332	large
Congo-Brazzaville	-	-	-	no	Panama	2020	Tc	79	large
Congo-Kinshasa	2003	Tc	17	medium	Northern America				
Equatorial Guinea	-	-	-	no	Canada*	1998	Us	28	medium
Gabon	-	-	-	no	United States*	2005	Tc	1,833	large
Sao Tome and Principe	-	-	-	no	South America				
Northern Africa					Argentina*	1974	Us	100	large
Algeria	2003	Us	13	small	Bolivia	2002	Cs	20	medium
Egypt	2010	Cs	31	medium	Brazil*	1989	Us	36	medium
Libya	-	-	-	no	Chile	1984	Cs	85	large
Morocco	2014	Cs	49	medium	Colombia	1988	Tc	26	medium
Sudan*	2002	Cs	33	medium	Ecuador	-	-	-	no
Tunisia	-	-	-	no	Guyana	-	-	-	no
Southern Africa					Paraguay	1997	Us	33	medium
Botswana	-	-	-	no	Peru	1997	Tc	518	large
Eswatini	1984	Tc	53	medium	Suriname	-	-	-	no
Lesotho	2001	Us	1	small	Uruguay	2005	Us	7	small
Namibia	-	-	-	no	Venezuela*	1993	Tc	100	large
South Africa	1984	Tc	64	large	Asia				
Western Africa					Central Asia				
Benin	-	-	-	no	Kazakhstan	1995	Us	112	large
Burkina Faso	-	-	-	no	Kyrgyzstan	2006	Us	4	small
Cabo Verde	1984	Tc	29	medium	Tajikistan	-	-	-	no
Ivory Coast	-	-	-	no	Turkmenistan	-	-	-	no
Gambia	2019	Cs	4	small	Uzbekistan	-	-	-	no
Ghana	2017	Cs	20	medium	Eastern Asia				
Guinea-Bissau	2018	Cs	3	small	China	1994	Tc	1,174	large
Guinea-Conakry	2000	Cs	4	small	Japan	1976	Tc	169	large
Liberia	-	-	-	no	Mongolia	2008	Cs	52	medium
Mali	-	-	-	no	North Korea	2018	Tc	86	large
Mauritania	2017	Cs	18	medium	Cs : Convective storm Es : Extra-tropical storm Ts : Tropical cyclone Us : Storm * : Country that establishes the federal governing system				
Niger	2002	Us	4	small					
Nigeria*	1999	Us	100	large					
Senegal	1999	Cs	165	large					

Table 3.6 List of maximum human damage from storms in 195 countries from 1971 to 2020 (cont'd)

Country	Year	Storm type	Maximum loss		Country	Year	Storm type	Maximum loss	
			Quantity	Level				Quantity	Level
South Korea	1987	Tc	483	large	Finland	-	-	-	no
South-eastern Asia					Iceland	-	-	-	no
Brunei	-	-	-	no	Ireland	1986	Tc	11	small
Cambodia	2020	Tc	38	medium	Latvia	1999	Es	6	small
Indonesia	1973	Tc	1,650	large	Lithuania	1993	Us	6	small
Laos	1995	Tc	26	medium	Norway	2011	Cs	4	small
Malaysia*	1996	Tc	270	large	Sweden	2013	Es	7	small
Myanmar	2008	Tc	138,366	large	United Kingdom	1991	Us	48	medium
Philippines	2013	Tc	7,354	large	Southern Europe				
Singapore	-	-	-	no	Albania	2002	Cs	6	small
Thailand	1989	Tc	458	large	Andorra	-	-	-	no
Timor-Leste	-	-	-	no	Bosnia and Herzegovina*	2005	Cs	4	small
Vietnam	1997	Tc	3,682	large	Croatia	2005	Cs	2	small
Southern Asia					Greece	1987	Us	350,000	medium
Afghanistan	2005	Us	260	large	Holy See	-	-	-	no
Bangladesh	1991	Tc	138,866	large	Italy	1987	Us	24	medium
Bhutan	1994	Tc	17	medium	Malta	-	-	-	no
India*	1977	Tc	14,204	large	Montenegro	-	-	-	no
Iran	1981	Us	200	large	North Macedonia	2005	Cs	1	small
Maldives	-	-	-	no	Portugal	1997	Us	29	medium
Nepal*	2014	Cs	83	large	San Marino	-	-	-	no
Pakistan*	1993	Tc	609	large	Serbia	-	-	-	no
Sri Lanka	1978	Tc	740	large	Slovenia	2007	Us	6	small
Western Asia					Spain	1997	Us	21	medium
Armenia	-	-	-	no	Western Europe				
Azerbaijan	-	-	-	no	Austria*	1984	Cs	12	small
Bahrain	-	-	-	no	Belgium*	1990	Us	10	small
Cyprus	-	-	-	no	France	1999	Es	88	large
Georgia	-	-	-	no	Germany*	1976	Us	82	large
Iraq*	-	-	-	no	Liechtenstein	-	-	-	no
Israel	1991	Us	5	small	Luxembourg	-	-	-	no
Jordan	2000	Us	9	small	Monaco	-	-	-	no
Kuwait	-	-	-	no	Netherlands	1990	Us	20	medium
Lebanon	1992	Cs	25	medium	Switzerland*	1999	Es	12	small
Oman	1977	Tc	105	large	Oceania				
Palestine	2015	Cs	4	small	Australia and New Zealand				
Qatar	-	-	-	no	Australia*	1974	Tc	65	large
Saudi Arabia	2016	Cs	3	small	New Zealand	1997	Tc	19	medium
Syria	2001	Cs	27	medium	Melanesia				
Turkey	1994	Cs	30	medium	Fiji	1973	Tc	59	medium
United Arab Emirates*	-	-	-	no	Papua New Guinea	2007	Tc	172	large
Yemen	2018	Tc	25	medium	Solomon Islands	1986	Tc	101	large
Europe					Vanuatu	1987	Tc	48	medium
Eastern Europe					Micronesia				
Belarus	1997	Tc	5	small	Federated States of Micronesia*	2002	Tc	47	medium
Bulgaria	2001	Us	2	small	Kiribati	1972	Tc	3	small
Czech	2007	Es	4	small	Marshall Islands	-	-	-	no
Hungary	1999	Cs	40	medium	Nauru	-	-	-	no
Moldova	1994	Cs	3	small	Palau	-	-	-	no
Poland	2007	Us	13	small	Polynesia				
Romania	2000	Cs	14	medium	Samoa	1991	Tc	13	small
Russia*	1984	Cs	400	large	Tonga	1982	Tc	6	small
Slovakia	2004	Us	2	small	Tuvalu	1972	Tc	6	small
Ukraine	1991	Cs	41	medium	Northern Europe				
Northern Europe					Cs : Convective storm Es : Extra-tropical storm				
Denmark	1981	Us	9	small	Ts : Tropical cyclone Us : Storm				
Estonia	-	-	-	no	* : Country that establishes the federal governing system				

Table 3.7 Definition of terms related to storms in EM-DAT

Term		Definition
Meteorological hazard		A hazard caused by short-lived, micro- to meso-scale extreme weather and atmospheric conditions that last from minutes to days. (e.g., storms, extreme temperatures, fog)
Storm	Convective storm (Cs)	A type of meteorological hazard generated by the heating of air and the availability of moist and unstable air masses. It ranges from localized thunderstorms (with heavy rain and/or hail, lightning, high winds, tornadoes) to meso-scale, multi-day events.
	Extratropical storm (Es)	A type of cyclonic system in the middle and high latitudes (also called a mid-latitude cyclone) that primarily gets its energy from the horizontal temperature contrasts (fronts) in the atmosphere. When associated with cold fronts, it may be particularly damaging (e.g., European winter/windstorms, Nor'easters).
	Tropical cyclone (Tc)	A type of cyclonic system that originates over tropical or subtropical waters. It is characterized by a warm-core, non-frontal synoptic-scale cyclone with a low-pressure center, spiral rain bands, and strong winds. Depending on their location, tropical cyclones are referred to as hurricanes (Atlantic and Northeast Pacific Ocean), typhoons (Northwest Pacific Ocean), or cyclones (South Pacific and Indian Ocean).
	Unclassifiable storm (Us)	A storm due to a meteorological hazard that was not able to be classified into any of the above storm types for some reasons.

Table 3.8 Level classification of maximum human damage per storm disaster

Loss level	Human loss range	Number of countries
No loss	0 people	54
Small loss	1 to 13 people	48
Medium loss	14 to 60 people	46
Large loss	more than 60 people	47
Total		195

Table 3.9 Breakdown of 195 countries for each level of maximum human damage from storms

Region	No loss	Small loss	Medium loss	Large loss	Total
Africa	20	13	14	7	54
Americas	3	6	11	15	35
Asia	16	5	8	19	48
Europe	12	20	9	3	44
Oceania	3	4	4	3	14
Total	54	48	46	47	195

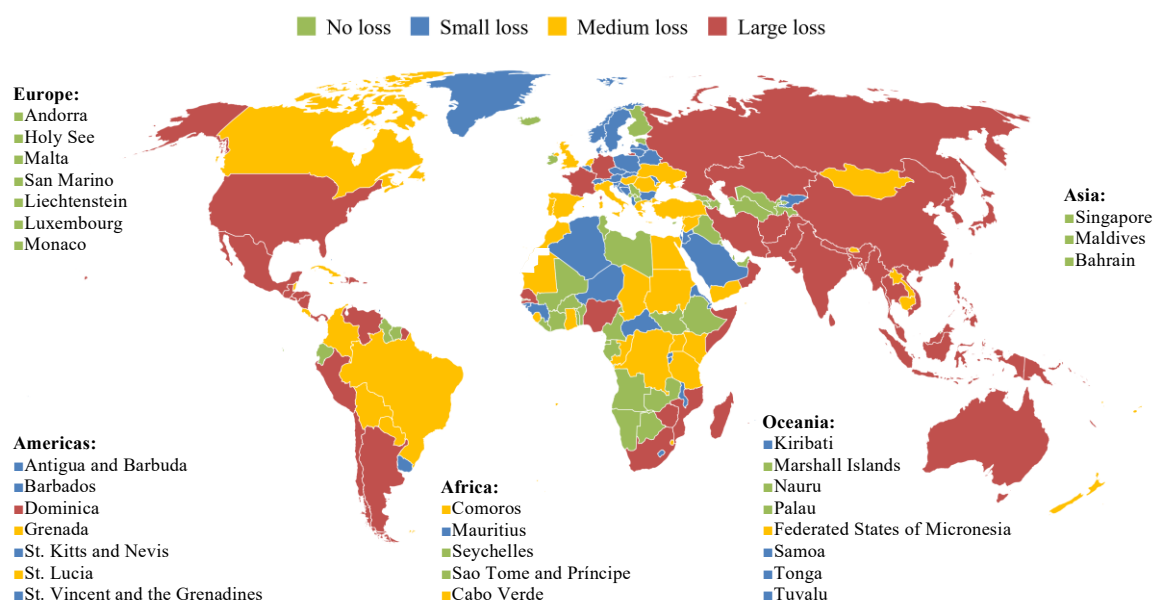


Figure 3.8 Distribution of each level of maximum human damage from storms in 195 countries

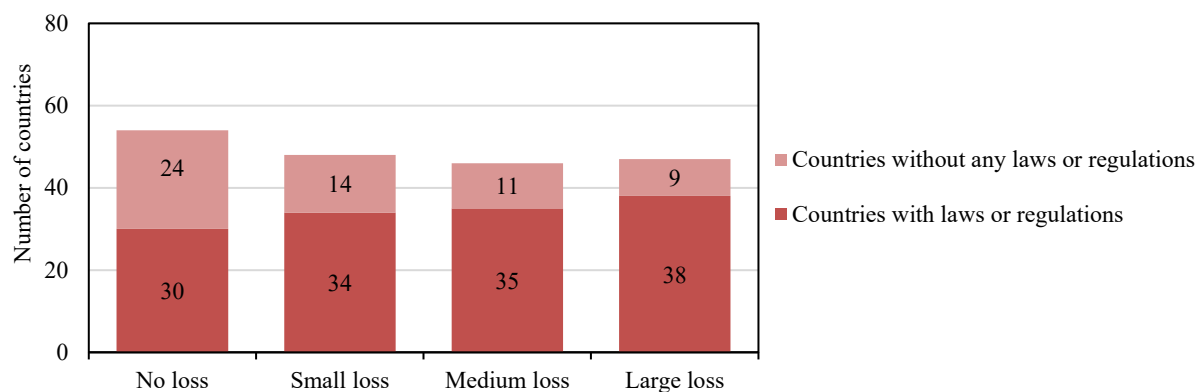


Figure 3.9 Breakdown of 195 countries on the establishment status of legal and regulatory frameworks for each level of maximum human damage from storms

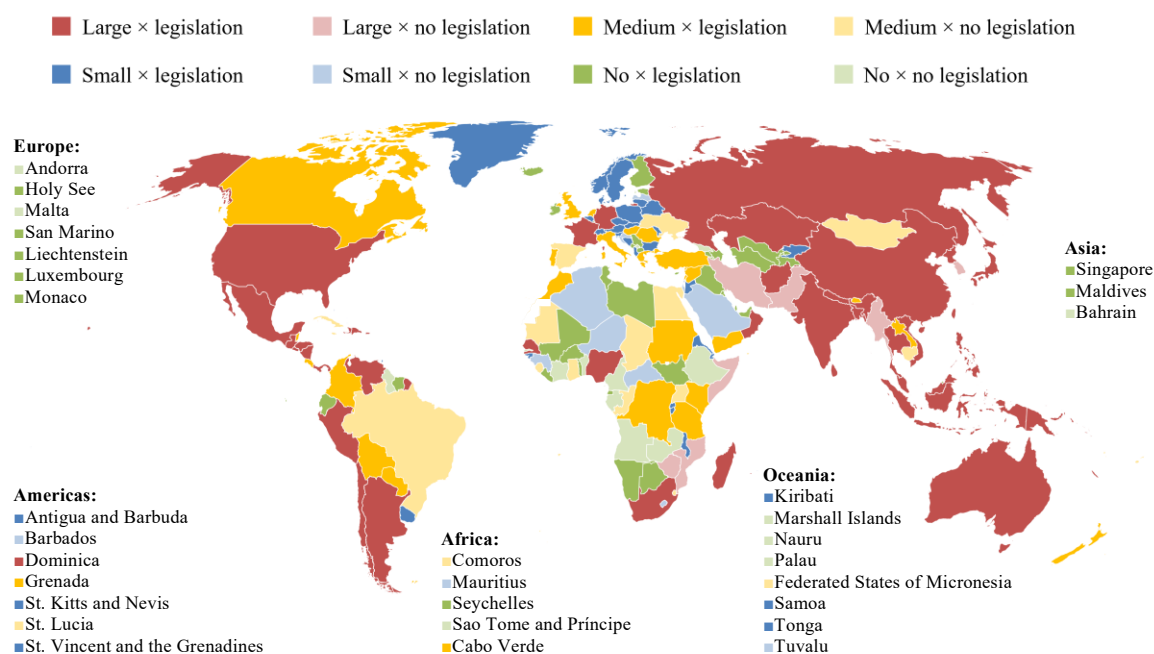


Figure 3.10 Distribution of the establishment status of legal and regulatory frameworks for each level of maximum human damage from storms in 195 countries

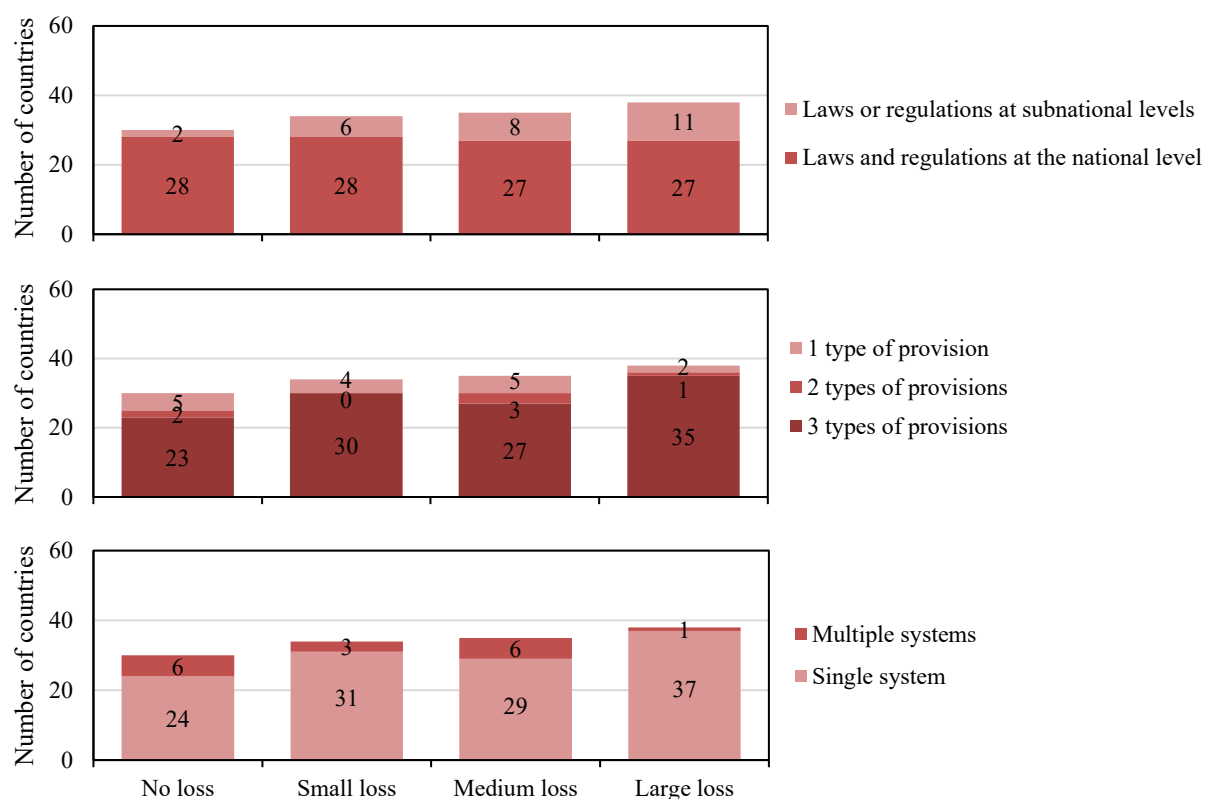


Figure 3.11 Breakdown of 137 countries establishing national or subnational legislation, defining one to three types of provisions, or accepting single or multiple systems for each level of maximum human damage from storms

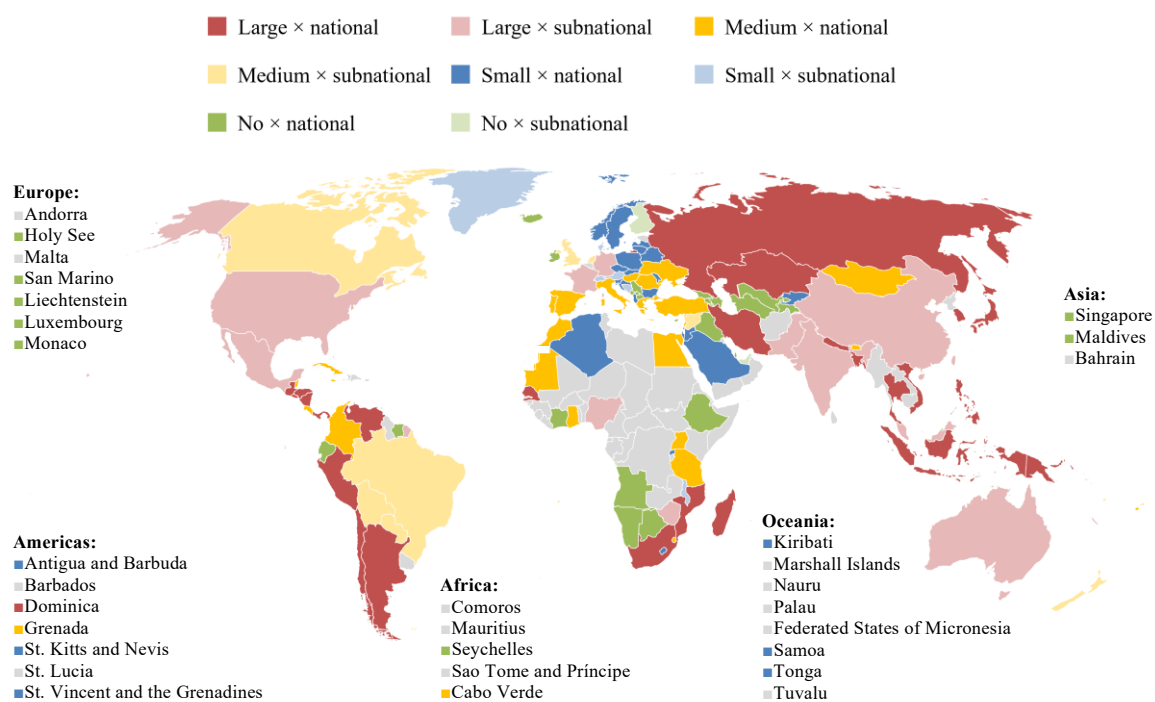


Figure 3.12 Distribution of national or subnational legislation for each level of maximum human damage from storms in 137 countries

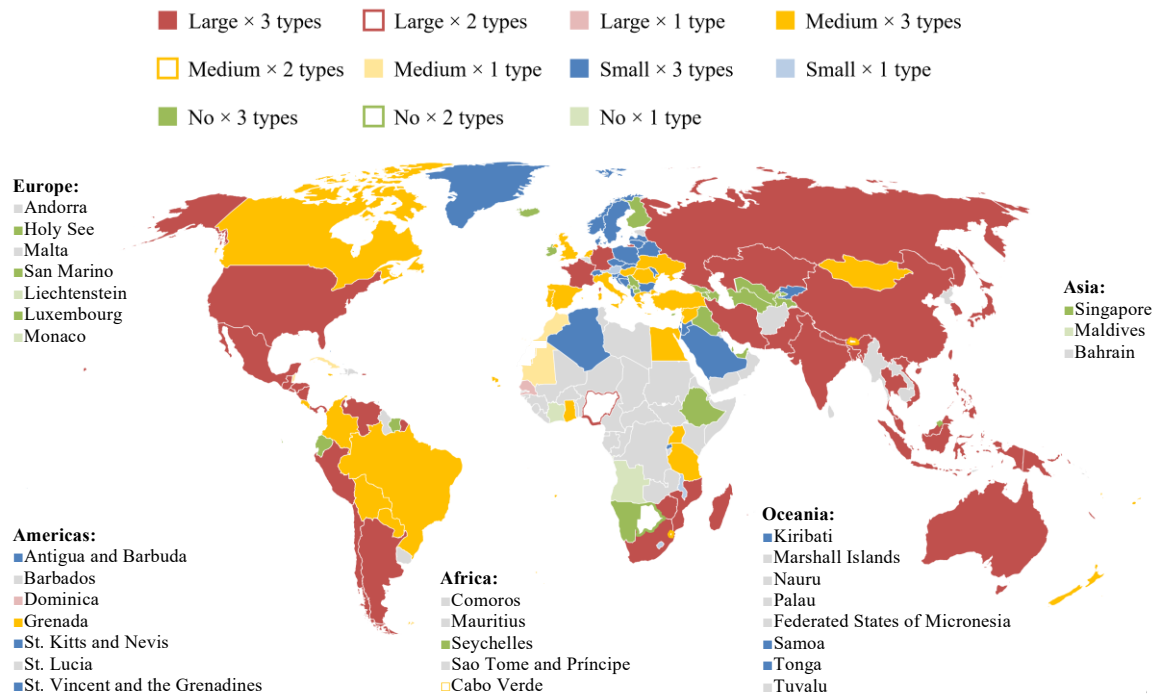


Figure 3.13 Distribution of one to three types of provisions for each level of maximum human damage from storms in 137 countries

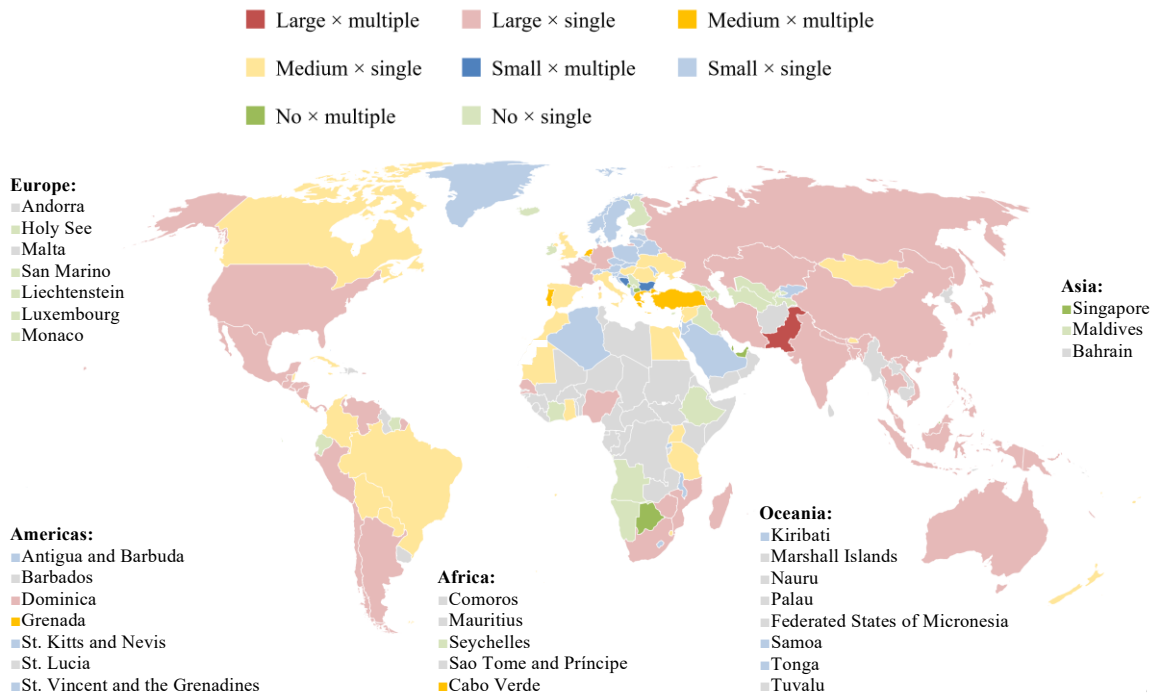


Figure 3.14 Distribution of single or multiple systems for each level of maximum human damage from storms in 137 countries

3.4.2 Economic damage from storms

Table 3.10 organizes maximum economic damage from storms in 195 countries. All damage and economic losses over the last 50 years from 1971 to 2020 are considered based on EM-DAT. The information may include the breakdown figures unadjusted for inflation by sectors: social, infrastructure, production, environment, and others (when available). Table 3.7 shows storm types and their definitions. This table suggests that all damage and losses due to storms in EM-DAT are not always limited to wind-related disasters. Asterisks: “*” and hyphens “-” in Table 3.10 denote that countries establish federal governmental systems, and that EM-DAT has not recorded any storm events that resulted in economic losses, respectively. According to Table 3.10, the largest economic loss was USD 125,000,000K recorded in the United States in 2005. This is followed by Japan with USD 17,000,000K in 2019, India with USD 13,500,000K in 2020, the Philippines with USD 10,000,000K in 2013, and China with USD 10,000,000K in 2019. They all are in tropical cyclone areas. Meanwhile, the largest economic loss due to convective storms, extra-tropical storms, and unclassifiable storms were USD 600,000K in Turkey in 2017, USD 8,000,000K in France in 1999, and USD 1,500,000K in Canada in 1998, respectively.

Table 3.10 also shows the level of maximum economic damage from storms. Table 3.11 shows the classification thereof. Here, economic losses are classified into four levels: no/low loss (less than USD 1K), moderate loss (between USD 1K and USD 60,000K), high loss (between USD 60,001K and USD 480,000K), and extreme loss (more than USD 480,000K). Of these, the last three levels are set to be almost the same number of countries for easy comparison. Table 3.12 shows the breakdown of 195 countries for each level of maximum economic damage from storms. Figure 3.15 shows this table on the world map. Here, the countries colored green, blue, yellow, and red represent those with no/low loss, moderate loss, high loss, and extreme loss, respectively. Also, this figure individually shows the status of 30 small countries with less than 5,000 km². The table and figure show that no/low loss areas spread across Africa, as well as extreme loss areas are not limited to the Americas or Asia with tropical cyclone areas but also extend to Europe.

(1) Overall trends

Figure 3.16 shows the breakdown of 195 countries on the legislation status for each country classification according to the levels of maximum economic damage per storm disaster. Parts colored dark and light green represent countries with and without any laws or regulations, respectively. This figure shows that 74 (=33+41) countries, which have not experienced any significant economic damage from storms, are classified into no/low loss. Of these, 41 countries, accounting for 21% of the total countries, enforce laws or regulations. On the other hand, 41 (=11+30), 40 (=9+31), and 40 (=5+35) countries, which have experienced significant economic damage from storms, are classified into moderate, high, and extreme losses, respectively. Of these, 25 (=11+9+5) countries, accounting for 13% of the total, do not enforce any laws or regulations, although their number slightly decreases with the rise of economic damage level.

Figure 3.17 shows Figure 3.16 on the world map. The countries colored red, yellow, blue, and green represent extreme, high, moderate, and no/low losses, respectively. The dark and light colored countries

represent those with and without any laws or regulations, respectively, as in Figure 3.16. Also, this figure individually shows the status of 30 small countries with less than 5,000 km². This figure shows that five countries: Dominican Republic, Suriname, North Korea, Myanmar, and Oman have suffered an extreme loss, as well as nine countries: Mauritius, Barbados, St. Lucia, Cambodia, Laos, Sri Lanka, Yemen, Estonia, and Belgium have suffered a high loss. However, they have not established any legislation. These facts suggest that economic damage from storms does not necessarily directly lead to the establishment of laws or regulations related to wind-resistant design of buildings.

(2) Trends in legal and regulatory jurisdictions or requirements

Figure 3.18 shows the breakdown of 137 countries establishing national or subnational legislation, defining one to three types of provisions, or accepting single or multiple systems for each country classification according to the level of maximum economic damage per storm disaster. The upper diagram shows the number of countries that enforce laws or regulations at the national or subnational levels (two greens, dark and light). The middle diagram shows the number of countries that define all three types of provisions, two types of provisions: wind-resistant design liability and wind load calculation methods, and only one type of provision: wind-resistant design liability (three greens from dark to light). The lower diagram shows the number of countries that accept single or multiple systems in either wind load calculation methods or reference wind speeds or pressures (two greens, light and dark).

None of the diagrams in Figure 3.18 reveal any significant relationships between the number of countries and the level of maximum economic damage. However, it is notable that the upper diagram shows that 14 countries of extreme loss enforce laws or regulations at the subnational level. In addition, the middle diagram shows that six (=3+3) countries of high or extreme loss define only wind-resistant design liability. These countries: Morocco, Cuba, Dominica, Belize, Lebanon, and Austria, have developed and adopted national codes or standards, or accepted specific internationally recognized codes or standards in practice, as shown in Chapter 2. Nevertheless, for these countries to reduce economic damage from storms as much as possible, both wind load calculation methods and reference wind speeds or pressures should be defined through laws or regulations, as well as an administrative system should be established to properly enforce them.

Figure 3.19 to Figure 3.21 show the upper to lower diagrams in Figure 3.18 on the world map. The countries colored red, yellow, blue, and green represent extreme, high, moderate, and no/low losses, respectively. The dark to light colored countries show the same as the contents shown in Figure 3.18. Also, these figures individually show the status of 30 small countries with less than 5,000 km². These figures also reveal some facts. For example, Figure 3.19 and Figure 3.20 show that 13 countries: Mexico, Canada, the United States, China, India, Pakistan, Denmark, the United Kingdom, France, Germany, the Netherlands, Switzerland, and Australia, which are classified as extreme loss, have subnational legislation with three types of provisions. Moreover, Figure 3.21 shows that two countries: Pakistan and the Netherlands, which are classified as extreme loss, have enforced multiple systems with three types of provisions at subnational levels. On the other hand, 18 countries: Mozambique, Bahamas, Grenada, Jamaica, El Salvador, Guatemala, Honduras, Nicaragua, Japan, South Korea, the Philippines, Vietnam, Bangladesh, Bulgaria, Sweden, Italy, Spain, and Fiji, which are classified as extreme loss, have the national

legislation with three types of provisions. Of these, two countries: Grenada and Bulgaria have accepted multiple systems under their respective jurisdictions.

Table 3.10 List of maximum economic damage from storms in 195 countries from 1971 to 2020

Country	Year	Storm type	Maximum loss		Country	Year	Storm type	Maximum loss	
			K USD	Level				K USD	Level
Africa					Sierra Leone	1975	Us	3,600	moderate
Eastern Africa					Togo	-	-	-	no/low
Burundi	-	-	-	no/low	Americas				
Comoros*	1983	Tc	23,000	moderate	Caribbean				
Djibouti	-	-	-	no/low	Antigua and Barbuda	1995	Tc	350,000	high
Eritrea	1993	Cs	5,165	moderate	Bahamas	2019	Tc	3,400,000	extreme
Ethiopia*	-	-	-	no/low	Barbados	1987	Tc	100,000	high
Kenya	-	-	-	no/low	Cuba	2016	Tc	2,600,000	extreme
Madagascar	1977	Tc	350,000	high	Dominica	2017	Tc	1,456,000	extreme
Malawi	-	-	-	no/low	Dominican Republic	1998	Tc	1,981,500	extreme
Mauritius	1975	Tc	200,000	high	Grenada	2004	Tc	889,000	extreme
Mozambique	2019	Tc	2,000,000	extreme	Haiti	2016	Tc	2,000,000	extreme
Rwanda	-	-	-	no/low	Jamaica	1988	Tc	1,000,000	extreme
Seychelles	2013	Tc	9,300	moderate	St. Kitts and Nevis*	1998	Tc	400,000	high
Somalia*	2013	Tc	2,000	moderate	St. Lucia	1980	Tc	87,990	high
South Sudan*	-	-	-	no/low	St. Vincent and the Grenadines	2010	Tc	25,000	moderate
Tanzania	-	-	-	no/low	Trinidad and Tobago	1974	Tc	5,000	moderate
Uganda	-	-	-	no/low	Central America				
Zambia	-	-	-	no/low	Belize	2000	Tc	277,460	high
Zimbabwe	2017	Tc	189,000	high	Costa Rica	1996	Tc	200,000	high
Middle Africa					El Salvador	2009	Tc	939,000	extreme
Angola	-	-	-	no/low	Guatemala	2005	Tc	988,300	extreme
Cameroon	-	-	-	no/low	Honduras	2020	Tc	5,000,000	extreme
Central African Republic	1981	Us	125	moderate	Mexico*	2005	Tc	5,000,000	extreme
Chad	1988	Cs	157	moderate	Nicaragua	1998	Tc	987,700	extreme
Congo-Brazzaville	-	-	-	no/low	Panama	1988	Tc	60,000	moderate
Congo-Kinshasa	-	-	-	no/low	Northern America				
Equatorial Guinea	-	-	-	no/low	Canada*	1998	Us	1,500,000	extreme
Gabon	-	-	-	no/low	United States*	2005	Tc	125,000,000	extreme
Sao Tome and Principe	-	-	-	no/low	South America				
Northern Africa					Argentina*	1993	Us	50,000	moderate
Algeria	-	-	-	no/low	Bolivia	-	-	-	no/low
Egypt	2015	Cs	100,000	high	Brazil*	2004	Tc	350,000	high
Libya	-	-	-	no/low	Chile	1977	Us	6,800	moderate
Morocco	2014	Cs	300,000	high	Colombia	2020	Tc	100,000	high
Sudan*	-	-	-	no/low	Ecuador	-	-	-	no/low
Tunisia	-	-	-	no/low	Guyana	-	-	-	no/low
Southern Africa					Paraguay	2013	Cs	25,000	moderate
Botswana	-	-	-	no/low	Peru	1997	Tc	12,000	moderate
Eswatini	1984	Tc	54,152	moderate	Suriname	-	-	-	no/low
Lesotho	-	-	-	no/low	Uruguay	2002	Us	25,000	moderate
Namibia	-	-	-	no/low	Venezuela*	1993	Tc	4,500	moderate
South Africa	1990	Cs	393,000	high	Asia				
Western Africa					Central Asia				
Benin	-	-	-	no/low	Kazakhstan	1995	Us	3,000	moderate
Burkina Faso	-	-	-	no/low	Kyrgyzstan	-	-	-	no/low
Cabo Verde	1982	Tc	3,000	moderate	Tajikistan	2001	Us	234	moderate
Ivory Coast	-	-	-	no/low	Turkmenistan	-	-	-	no/low
Gambia	-	-	-	no/low	Uzbekistan	-	-	-	no/low
Ghana	-	-	-	no/low	Eastern Asia				
Guinea-Bissau	-	-	-	no/low	China	2019	Tc	10,000,000	extreme
Guinea-Conakry	-	-	-	no/low	Japan	2019	Tc	17,000,000	extreme
Liberia	-	-	-	no/low	Mongolia	2000	Us	80,000	high
Mali	-	-	-	no/low	North Korea	2000	Tc	6,000,000	extreme
Mauritania	-	-	-	no/low	Cs : Convective storm Es : Extra-tropical storm				
Niger	-	-	-	no/low	Ts : Tropical cyclone Us : Storm				
Nigeria*	2012	Cs	1,000	moderate	* : Country that establishes the federal governing system				
Senegal	-	-	-	no/low					

Table 3.10 List of maximum economic damage from storms in 195 countries from 1971 to 2020 (cont'd)

Country	Year	Storm type	Maximum loss		Country	Year	Storm type	Maximum loss	
			K USD	Level				K USD	Level
South Korea	2003	Tc	4,500,000	extreme	Finland	1990	Us	5,000	moderate
South-eastern Asia					Iceland	-	-	-	no/low
Brunei	-	-	-	no/low	Ireland	2000	Es	100,000	high
Cambodia	2020	Tc	100,000	high	Latvia	2005	Es	325,000	high
Indonesia	2012	Cs	1,000	moderate	Lithuania	2005	Es	30,000	moderate
Laos	1993	Us	302,151	high	Norway	2005	Es	130,000	high
Malaysia*	1996	Tc	52,000	moderate	Sweden	2005	Es	2,800,000	extreme
Myanmar	2008	Tc	4,000,000	extreme	United Kingdom	2004	Tc	3,430,080	extreme
Philippines	2013	Tc	10,000,000	extreme	Southern Europe				
Singapore	-	-	-	no/low	Albania	-	-	-	no/low
Thailand	1989	Tc	452,000	high	Andorra	-	-	-	no/low
Timor-Leste	-	-	-	no/low	Bosnia and Herzegovina*	-	-	-	no/low
Vietnam	2017	Tc	1,430,000	extreme	Croatia	2017	Cs	161,000	high
Southern Asia					Greece	1987	Us	350,000	high
Afghanistan	2005	Us	5,000	moderate	Holy See	-	-	-	no/low
Bangladesh	2007	Tc	2,300,000	extreme	Italy	2018	Es	1,100,000	extreme
Bhutan	-	-	-	no/low	Malta	-	-	-	no/low
India*	2020	Tc	13,500,000	extreme	Montenegro	-	-	-	no/low
Iran	1993	Cs	15,000	moderate	North Macedonia	-	-	-	no/low
Maldives	1991	Cs	30,000	moderate	Portugal	2010	Es	270,000	high
Nepal*	1986	Us	3,600	moderate	San Marino	-	-	-	no/low
Pakistan*	2007	Tc	1,620,000	extreme	Serbia	-	-	-	no/low
Sri Lanka	2017	Tc	346,000	high	Slovenia	2007	Us	292,000	high
Western Asia					Spain	2021	Es	1,900,000	extreme
Armenia	2013	Cs	60,000	moderate	Western Europe				
Azerbaijan	-	-	-	no/low	Austria*	2009	Cs	500,000	extreme
Bahrain	-	-	-	no/low	Belgium*	2007	Es	450,000	high
Cyprus	2003	Cs	10,000	moderate	France	1999	Es	8,000,000	extreme
Georgia	2012	Cs	91,000	high	Germany*	2007	Es	5,500,000	extreme
Iraq*	-	-	-	no/low	Liechtenstein	-	-	-	no/low
Israel	2000	Us	2,750	moderate	Luxembourg	1990	Us	90,000	high
Jordan	-	-	-	no/low	Monaco	-	-	-	no/low
Kuwait	-	-	-	no/low	Netherlands	2017	Tc	2,500,000	extreme
Lebanon	1992	Cs	155,000	high	Switzerland*	1999	Es	1,500,000	extreme
Oman	2007	Tc	3,900,000	extreme	Oceania				
Palestine	-	-	-	no/low	Australia and New Zealand				
Qatar	-	-	-	no/low	Australia*	2017	Tc	2,700,000	extreme
Saudi Arabia	2016	Cs	50,000	moderate	New Zealand	1992	Cs	51,500	moderate
Syria	-	-	-	no/low	Melanesia				
Turkey	2017	Cs	600,000	extreme	Fiji	2016	Tc	600,000	extreme
United Arab Emirates*	-	-	-	no/low	Papua New Guinea	1993	Tc	1,500	moderate
Yemen	2015	Tc	200,000	high	Solomon Islands	1986	Tc	20,000	moderate
Europe					Vanuatu	2015	Tc	449,400	high
Eastern Europe					Micronesia				
Belarus	1997	Tc	33,000	moderate	Federated States of Micronesia*	2015	Tc	11,000	moderate
Bulgaria	2014	Cs	545,000	extreme	Kiribati	-	-	-	no/low
Czech	2007	Es	150,000	high	Marshall Islands	-	-	-	no/low
Hungary	2006	Us	10,000	moderate	Nauru	-	-	-	no/low
Moldova	2000	Cs	31,600	moderate	Palau	-	-	-	no/low
Poland	2017	Cs	275,000	high	Polynesia				
Romania	2017	Cs	7,300	moderate	Samoa	1991	Tc	278,000	high
Russia*	1998	Us	160,000	high	Tonga	2020	Tc	111,000	high
Slovakia	2004	Us	383,300	high	Tuvalu	-	-	-	no/low
Ukraine	2000	Us	120,000	high	Cs : Convective storm Es : Extra-tropical storm Ts : Tropical cyclone Us : Storm * : Country that establishes the federal governing system				
Northern Europe									
Denmark	1999	Es	2,604,939	extreme					
Estonia	2005	Es	130,000	high					

Table 3.11 Level classification of maximum economic damage per storm disaster

Loss level	Economic loss range	Number of countries
No/Low loss	less than USD 1K	74
Moderate loss	between USD 1K and USD 60,000K	41
High loss	between USD 60,001K and USD 480,000K	40
Extreme loss	more than USD 480,000K	40
Total		195

Table 3.12 Breakdown of 195 countries for each level of maximum economic damage from storms

Region	No/low loss	Moderate loss	High loss	Extreme loss	Total
Africa	37	10	6	1	54
Americas	4	9	8	14	35
Asia	16	12	8	12	48
Europe	12	6	15	11	44
Oceania	5	4	3	2	14
Total	74	41	40	40	195

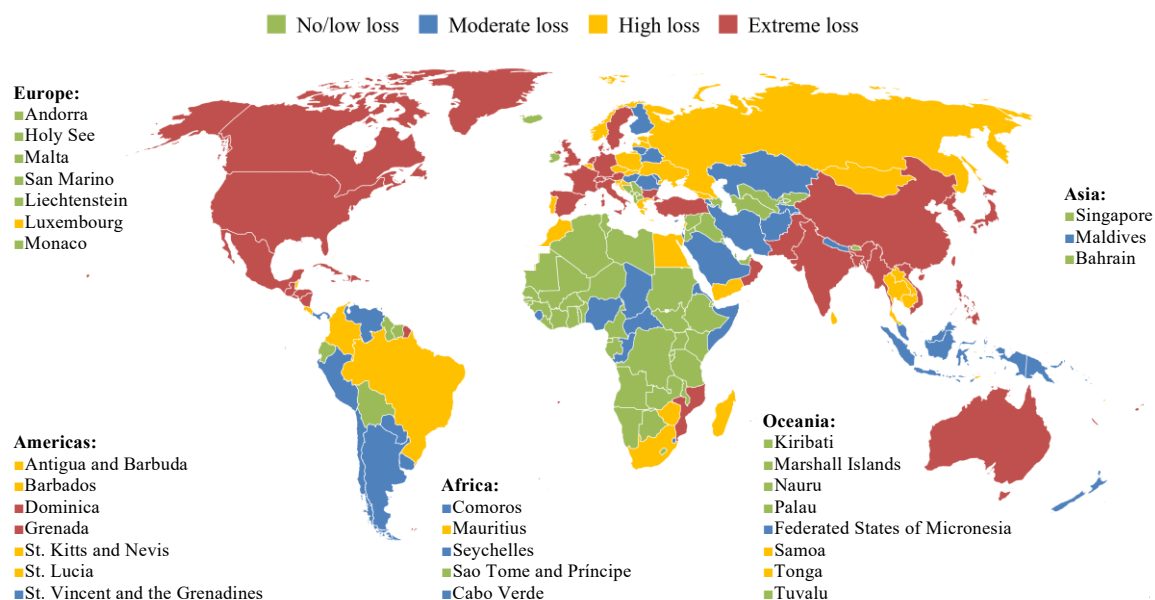


Figure 3.15 Distribution of each level of maximum economic damage from storms in 195 countries

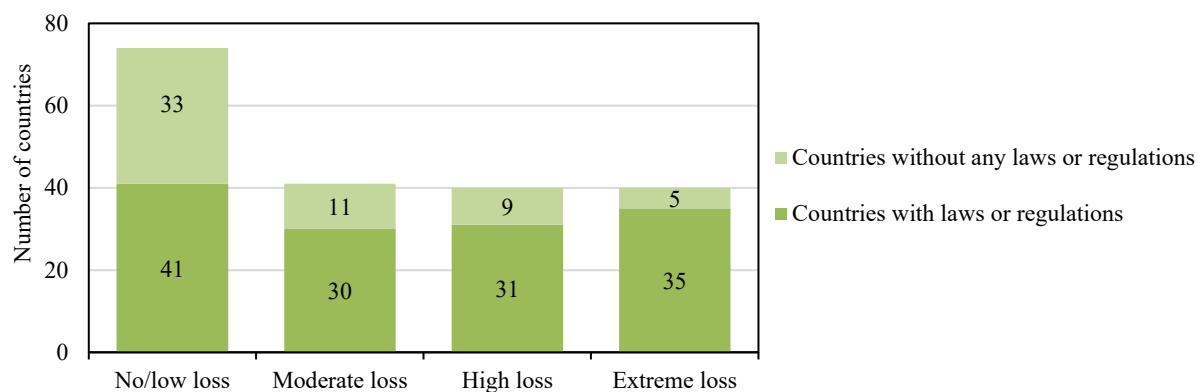


Figure 3.16 Breakdown of 195 countries on the establishment status of legal and regulatory frameworks for each level of maximum economic damage from storms

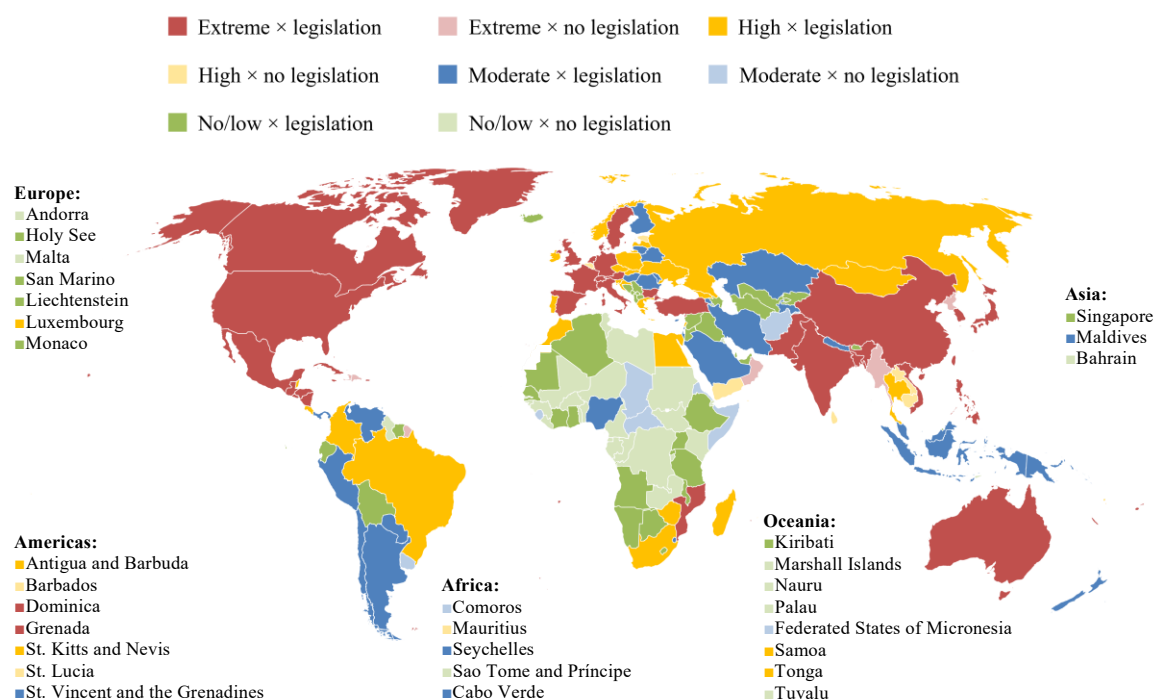


Figure 3.17 Distribution of the establishment status of legal and regulatory frameworks for each level of maximum economic damage from storms in 195 countries

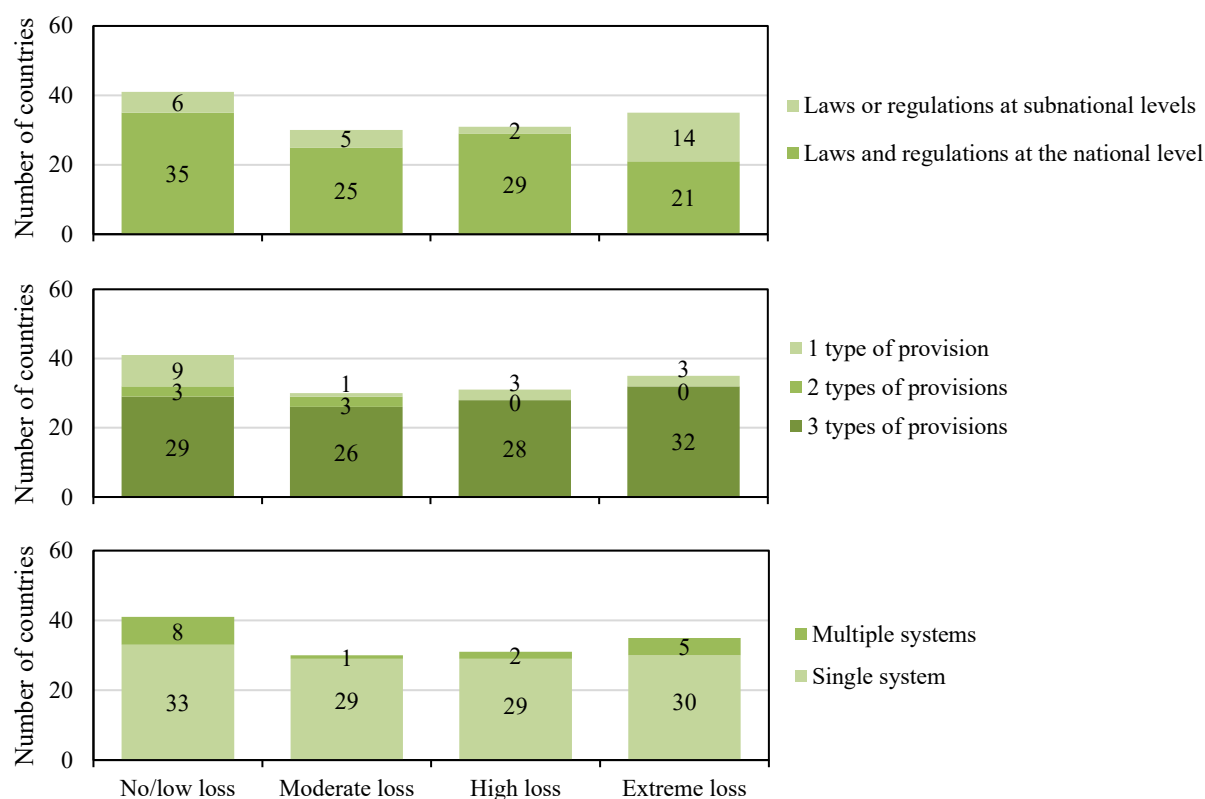


Figure 3.18 Breakdown of 137 countries establishing national or subnational legislation, defining one to three types of provisions, or accepting single or multiple systems for each level of maximum economic damage from storms

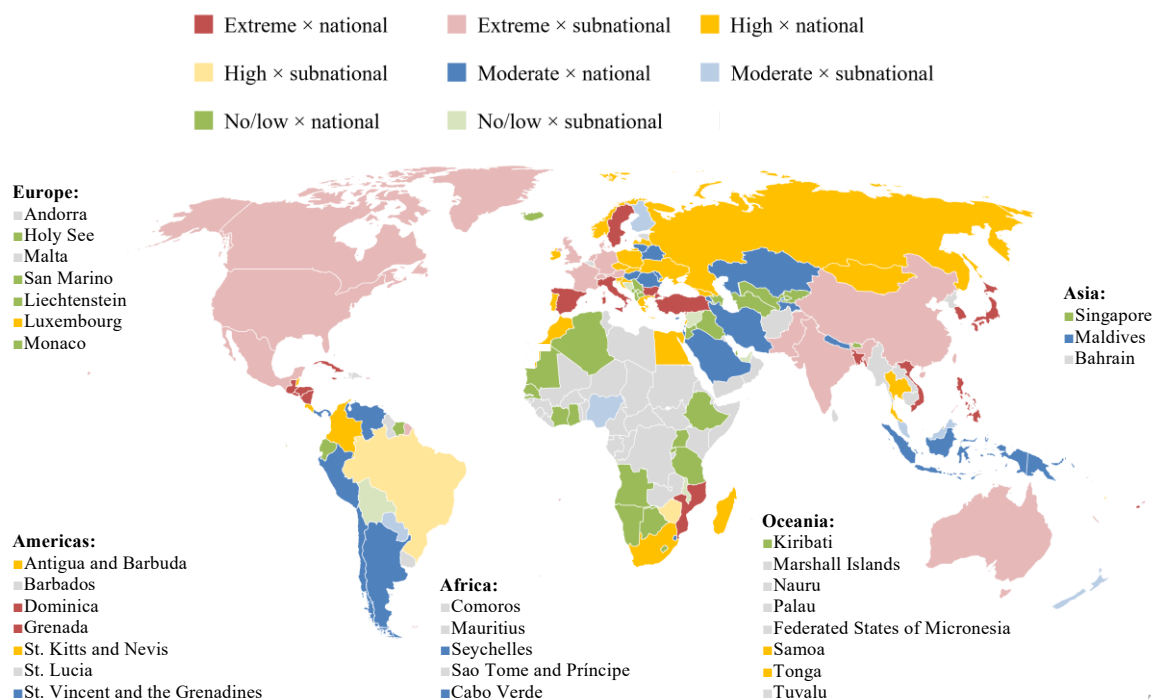


Figure 3.19 Distribution of national or subnational legislation for each level of maximum economic damage from storms in 137 countries

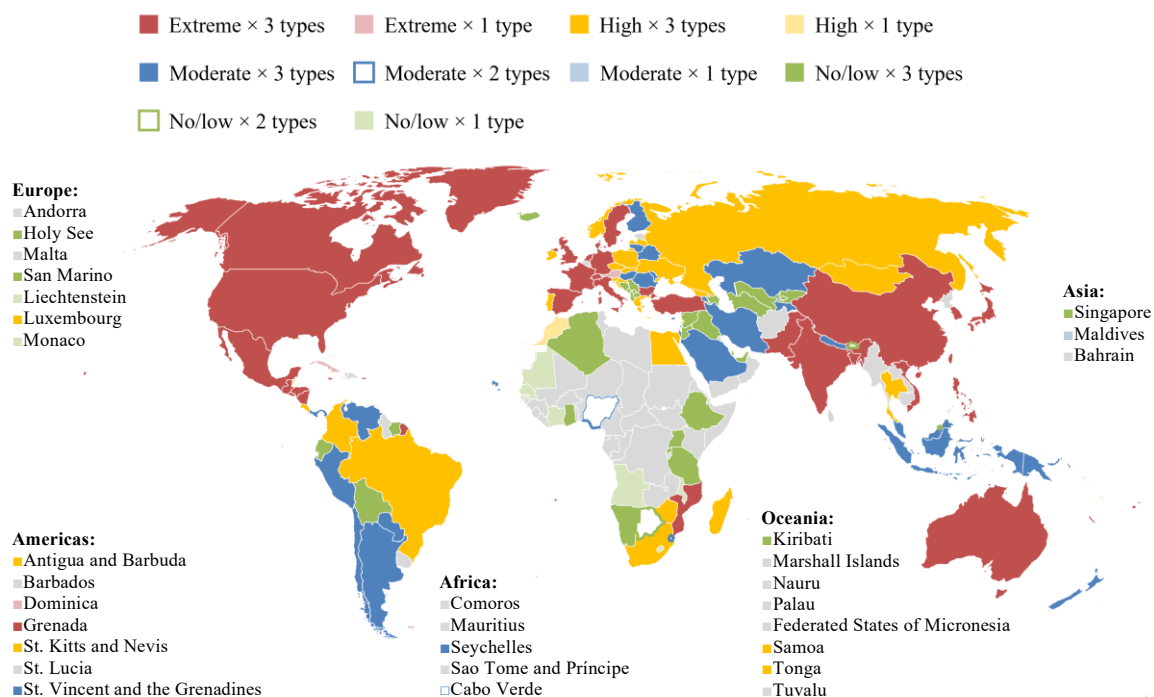


Figure 3.20 Distribution of one to three types of provisions for each level of maximum economic damage from storms in 137 countries

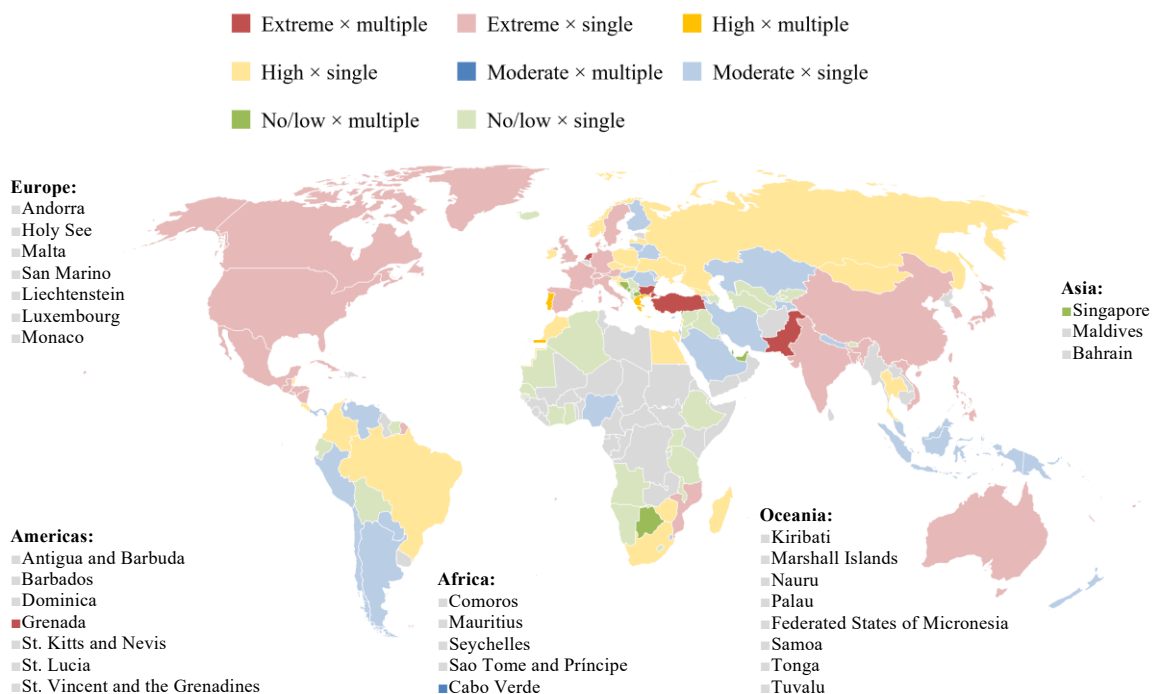


Figure 3.21 Distribution of single or multiple systems for each level of maximum economic damage from storms in 137 countries

3.4.3 Economic developments of countries

Table 3.13 organizes gross national income (GNI) per capita in 195 countries. It is the dollar value of a country's final income in a year divided by its population. However, it is not publicly available in the Holy See. It is the nominal values in 2020 according to the Atlas method, which is an indicator of income developed by the World Bank. However, the most recent GNI per capita before 2020 is considered if the GNI per capita in 2020 is not published. Asterisks: "*" and hyphens "-" in this table denote that countries establish federal governmental systems, and that no relevant information was available, respectively. According to this table, the lowest income was USD 220 for Burundi in 2020 and the highest income was USD 116,600 for Liechtenstein in 2005.

Table 3.13 also shows the level of GNI per capita. Table 3.14 shows the classification thereof. Here, GNI per capita is classified into four levels: low income (USD 1,045 or less), lower middle income (between USD 1,046 and USD 4,095), upper middle income (between USD 4,096 and USD 12,695), and high income (USD 12,696 or more). This classification is based on the World Bank Country and Lending Groups (WB 2021). However, it should be noted that Jordan is classified as an upper middle income country despite having less than USD 4,095. Furthermore, Venezuela is classified as an upper middle income country based on 2014 information although it has been officially unclassified in the recent period due to a lack of available data. Table 3.15 shows the breakdown of 194 countries excluding the Holy See for each economic developmental level of countries. Figure 3.22 shows this table on the world map. Here, the countries colored green, blue, yellow, and red represent those with high income, upper middle income, lower middle income, and low income, respectively. Also, this figure individually shows the status of 30 small countries with less than 5,000 km². The table and figure show that low income areas spread across Africa, 46 countries in which are grouped into either low income or lower middle income. At the same time, high income areas extend to Europe, 42 countries in which are grouped into either upper middle income or high income. Incidentally, only one high income country in Africa is Seychelles and only one lower middle income country in Europe is Ukraine.

(1) Overall trends

Figure 3.23 shows the breakdown of 194 countries on the status of legislation for each country classification according to the levels of economic development of countries. Parts colored dark and light blue represent countries with and without any laws or regulations, respectively. This figure shows that 129 (=38+45+46) countries, which enforce laws or regulations, are classified into lower middle, upper middle, and high income. Just seven countries are classified as low income. Their percentages are 67% and 3.5% of the total, respectively. Their numbers drastically increase from low to lower middle incomes and then slightly increase from lower middle to high incomes.

Figure 3.24 shows Figure 3.23 on the world map. The countries colored red, yellow, blue, and green represent low, lower middle, upper middle, and high incomes, respectively. The dark and light colored countries represent those with and without any laws or regulations, respectively, as in Figure 3.23. Also, this figure individually shows the status of 30 small countries with less than 5,000 km². This figure shows that, especially in Africa and Asia, low and lower middle income countries overlap with countries without

any legislation. Countries classified as low income, most of which are also classified as LDCs, are confronting severe structural impediments to sustainable development, and therefore have difficulty in having a comprehensive ability to undertake legal, institutional, technical, and financial means to achieve safe building constructions. These facts suggest that at least a lower middle income level of economic development is required for the establishment of laws or regulations.

(2) Trends in legal and regulatory jurisdictions or requirements

Figure 3.25 shows the breakdown of 137 countries establishing national or subnational legislation, defining one to three types of provisions, or accepting single or multiple systems for each country classification according to the level of economic development of countries. The upper diagram shows the number of countries that enforce laws or regulations at the national or subnational levels (two blues, dark and light). The middle diagram shows the number of countries that define all three types of provisions, two types of provisions: wind-resistant design liability and wind load calculation methods, and only one type of provision: wind-resistant design liability (three blues from dark to light). The lower diagram shows the number of countries that accept single or multiple systems in either wind load calculation methods or reference wind speeds or pressures (two blues, light and dark).

This figure reveals some relationships between the number of countries and the level of GNI per capita. The upper diagram shows that the difference in the number of countries classified as low or lower middle incomes, which have established laws or regulations at the national level, is more remarkable than that shown in the overall trend. Also, this number significantly decreases from upper middle to high incomes, unlike the overall trend. These differences are because the number of countries with laws or regulations at subnational levels roughly tends to increase with the rise of economic developmental level. The lower diagram shows that the number of countries that accept multiple systems also increases with the rise of economic developmental level. These facts suggest that higher income countries are better able to enforce laws or regulations at subnational levels and properly use multiple systems than are lower income countries. On the other hand, the middle diagram shows that more countries in lower middle income level define only one type of provision than those in any other income level. The same is true for countries that define two types of provisions. Countries on this level can recognize and proclaim the importance of wind-resistant design for sustainable developments of buildings as higher income countries do. These facts suggest that a little more financial or technical support by higher income countries or international organizations could help these countries fully establish laws or regulations.

Figure 3.26 to Figure 3.28 show the upper to lower diagrams in Figure 3.25 on the world map. The countries colored red, yellow, blue, and green represent low, lower middle, upper middle, and high incomes, respectively. Of these, the dark to light colored countries show the same as the contents shown in Figure 3.25. Also, these figures individually show the status of 30 small countries with less than 5,000 km². These figures reveal some facts. For example, Figure 3.26 and Figure 3.27 show that the countries classified as low income but having the national legislation with three types of provisions, namely five countries: Ethiopia, Madagascar, Mozambique, Rwanda, and Uganda, are localized in the Eastern Africa. Also, Figure 3.28 shows that two countries: Cabo Verde and Pakistan, which are classified as lower middle income, have accepted multiple systems like some countries classified as higher incomes.

Table 3.13 List of GNI per capita in 195 countries in 2020

Country	GNI per capita		Income level	Country	GNI per capita		Income level
	Year	USD			Year	USD	
Africa				Sierra Leone	2020	490	Low
Eastern Africa				Togo	2020	900	Low
Burundi	2020	220	low	Americas			
Comoros*	2020	1,520	lower middle	Caribbean			
Djibouti	2020	2,830	lower middle	Antigua and Barbuda	2020	14,530	high
Eritrea	2011	610	low	Bahamas	2020	23,500	high
Ethiopia*	2020	880	low	Barbados	2020	16,230	high
Kenya	2020	1,900	lower middle	Cuba	2019	8,920	upper middle
Madagascar	2020	460	low	Dominica	2020	7,140	upper middle
Malawi	2020	580	low	Dominican Republic	2020	7,170	upper middle
Mauritius	2020	9,940	upper middle	Grenada	2020	7,880	upper middle
Mozambique	2020	470	low	Haiti	2020	1,330	lower middle
Rwanda	2020	760	low	Jamaica	2020	4,900	upper middle
Seychelles	2020	14,040	high	St. Kitts and Nevis*	2020	19,420	high
Somalia*	2020	410	low	St. Lucia	2020	8,590	upper middle
South Sudan*	2015	1,040	low	St. Vincent and the Grenadines	2020	8,260	upper middle
Tanzania	2020	1,050	lower middle	Trinidad and Tobago	2020	13,830	high
Uganda	2020	740	low	Central America			
Zambia	2020	1,130	lower middle	Belize	2020	5,210	lower middle
Zimbabwe	2020	1,460	lower middle	Costa Rica	2020	11,460	upper middle
Middle Africa				El Salvador	2020	3,740	lower middle
Angola	2020	1,740	lower middle	Guatemala	2020	4,490	upper middle
Cameroon	2020	1,520	lower middle	Honduras	2020	2,150	lower middle
Central African Republic	2020	460	low	Mexico*	2020	8,750	upper middle
Chad	2020	630	low	Nicaragua	2020	1,740	lower middle
Congo-Brazzaville	2020	1,760	lower middle	Panama	2020	12,470	upper middle
Congo-Kinshasa	2020	540	low	Northern America			
Equatorial Guinea	2020	5,100	upper middle	Canada*	2020	43,540	high
Gabon	2020	6,830	upper middle	United States*	2020	64,650	high
Sao Tome and Principe	2020	2,100	lower middle	South America			
Northern Africa				Argentina*	2020	9,010	upper middle
Algeria	2020	3,600	lower middle	Bolivia	2020	3,120	lower middle
Egypt	2020	2,860	lower middle	Brazil*	2020	7,820	upper middle
Libya	2020	7,890	upper middle	Chile	2020	12,990	high
Morocco	2020	3,250	lower middle	Colombia	2020	5,820	upper middle
Sudan*	2020	630	low	Ecuador	2020	5,560	upper middle
Tunisia	2020	3,230	lower middle	Guyana	2020	6,600	upper middle
Southern Africa				Paraguay	2020	5,550	upper middle
Botswana	2020	6,010	upper middle	Peru	2020	6,000	upper middle
Eswatini	2020	3,360	lower middle	Suriname	2020	4,500	upper middle
Lesotho	2020	1,150	lower middle	Uruguay	2020	15,950	high
Namibia	2020	4,650	upper middle	Venezuela*	2014	13,010	(upper middle)
South Africa	2020	6,090	upper middle	Asia			
Western Africa				Central Asia			
Benin	2020	1,230	lower middle	Kazakhstan	2020	8,710	upper middle
Burkina Faso	2020	750	low	Kyrgyzstan	2020	1,180	lower middle
Cabo Verde	2020	2,920	lower middle	Tajikistan	2020	1,050	lower middle
Ivory Coast	2020	2,240	lower middle	Turkmenistan	2019	6,970	upper middle
Gambia	2020	700	low	Uzbekistan	2020	1,740	lower middle
Ghana	2020	2,230	lower middle	Eastern Asia			
Guinea-Bissau	2020	740	low	China	2020	10,520	upper middle
Guinea-Conakry	2020	960	low	Japan	2020	40,810	high
Liberia	2020	600	low	Mongolia	2020	3,720	lower middle
Mali	2020	790	low	North Korea	-	-	low
Mauritania	2020	1,790	lower middle	*: Country that establishes the federal governing system			
Niger	2020	550	low				
Nigeria*	2020	2,020	lower middle				
Senegal	2020	1,460	lower middle				

Table 3.13 List of gross national income (GNI) per capita in 195 countries in 2020 (cont'd)

Country	GNI per capita		Income level	Country	GNI per capita		Income level
	Year	USD			Year	USD	
South Korea	2020	33,040	high	Finland	2020	50,100	high
South-eastern Asia				Iceland	2019	72,930	high
Brunei	2020	31,210	high	Ireland	2020	65,330	high
Cambodia	2020	1,530	lower middle	Latvia	2020	18,240	high
Indonesia	2020	3,900	lower middle	Lithuania	2020	19,680	high
Laos	2020	2,470	lower middle	Norway	2020	77,880	high
Malaysia*	2020	10,320	upper middle	Sweden	2020	54,740	high
Myanmar	2020	1,370	lower middle	United Kingdom	2020	38,590	high
Philippines	2020	3,350	lower middle	Southern Europe			
Singapore	2020	55,010	high	Albania	2020	5,260	upper middle
Thailand	2020	6,900	upper middle	Andorra	2019	46,530	high
Timor-Leste	2020	2,100	lower middle	Bosnia and Herzegovina*	2020	6,030	upper middle
Vietnam	2020	3,450	lower middle	Croatia	2020	14,820	high
Southern Asia				Greece	2019	19,690	high
Afghanistan	2020	500	low	Holy See	-	-	-
Bangladesh	2020	2,300	lower middle	Italy	2020	32,410	high
Bhutan	2020	2,840	lower middle	Malta	2020	26,440	high
India*	2020	1,890	lower middle	Montenegro	2020	7,900	upper middle
Iran	2020	3,290	lower middle	North Macedonia	2020	5,730	upper middle
Maldives	2020	6,780	upper middle	Portugal	2020	21,850	high
Nepal*	2020	1,180	lower middle	San Marino	2020	41,450	high
Pakistan*	2020	1,420	lower middle	Serbia	2020	7,440	upper middle
Sri Lanka	2020	3,930	lower middle	Slovenia	2020	25,400	high
Western Asia				Spain	2019	30,330	high
Armenia	2020	4,470	upper middle	Western Europe			
Azerbaijan	2020	4,480	upper middle	Austria*	2020	48,990	high
Bahrain	2020	22,950	high	Belgium*	2020	46,030	high
Cyprus	2020	26,600	high	France	2020	39,440	high
Georgia	2020	4,260	upper middle	Germany*	2020	48,050	high
Iraq*	2020	4,720	upper middle	Liechtenstein	2009	116,600	high
Israel	2020	43,310	high	Luxembourg	2020	79,580	high
Jordan	2020	4,070	upper middle	Monaco	-	-	high
Kuwait	2019	34,290	high	Netherlands	2020	50,170	high
Lebanon	2020	6,400	upper middle	Switzerland*	2020	82,740	high
Oman	2020	17,110	high	Oceania			
Palestine	2020	3,700	lower middle	Australia and New Zealand			
Qatar	2020	58,370	high	Australia*	2020	53,620	high
Saudi Arabia	2020	21,540	high	New Zealand	2020	41,480	high
Syria	2020	760	low	Melanesia			
Turkey	2020	9,070	upper middle	Fiji	2020	4,680	upper middle
United Arab Emirates*	2020	41,770	high	Papua New Guinea	2020	2,470	lower middle
Yemen	2018	840	low	Solomon Islands	2020	2,340	lower middle
Europe				Vanuatu	2020	2,780	lower middle
Eastern Europe				Micronesia			
Belarus	2020	6,400	upper middle	Federated States of Micronesia*	2020	4,070	lower middle
Bulgaria	2020	9,520	upper middle	Kiribati	2020	2,740	lower middle
Czech	2020	21,800	high	Marshall Islands	2020	6,690	upper middle
Hungary	2020	16,030	high	Nauru	2020	15,240	high
Moldova	2020	4,490	upper middle	Palau	2020	14,640	high
Poland	2020	15,300	high	Polynesia			
Romania	2020	12,700	upper middle	Samoa	2020	4,000	lower middle
Russia*	2020	10,740	upper middle	Tonga	2020	5,200	upper middle
Slovakia	2020	19,180	high	Tuvalu	2020	6,750	upper middle
Ukraine	2020	3,570	lower middle				
Northern Europe							
Denmark	2020	62,710	high				
Estonia	2020	23,570	high				

*: Country that establishes the federal governing system

Table 3.14 Level classification of GNI per capita

Income level	GNI per capita range	Number of countries
Low income	USD 1,045 or less	27
Lower middle income	between USD 1,046 and USD 4,095	55
Upper middle income	between USD 4,096 and USD 12,695	54
High income	USD 12,696 or more	58
Total		194

Table 3.15 Breakdown of 194 countries for each level of economic development of countries

Region	Low income	Lower middle income	Upper middle income	High income	Total
Africa	23	23	7	1	54
Americas	0	6	20	9	35
Asia	4	19	13	12	48
Europe	0	1	10	32	43
Oceania	0	6	4	4	14
Total	27	55	54	58	194

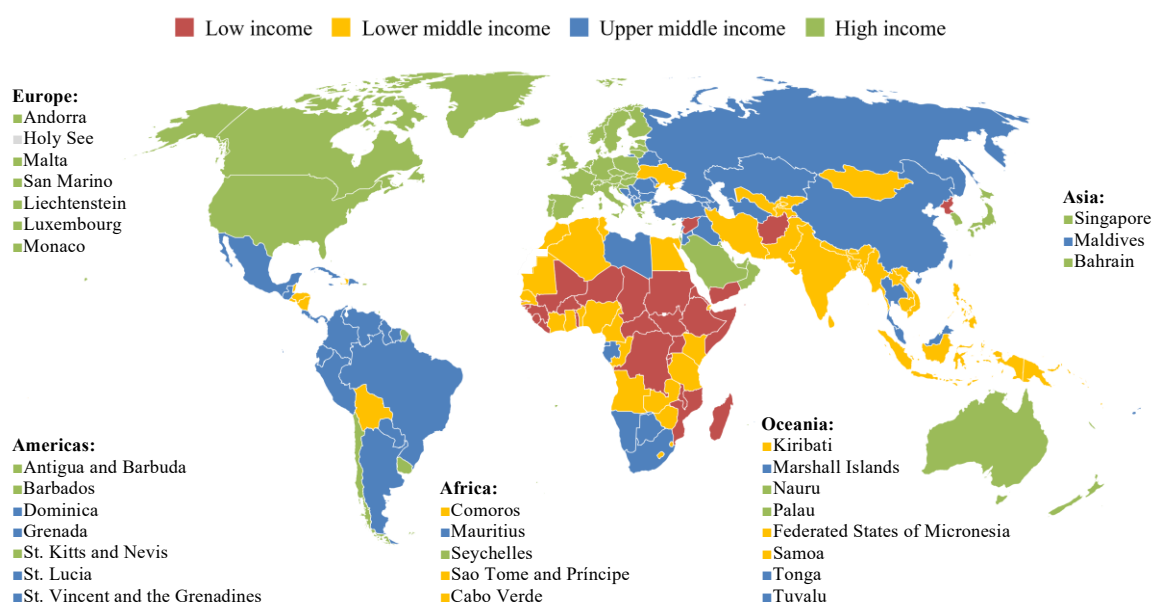


Figure 3.22 Distribution of each level of economic development of countries in 194 countries

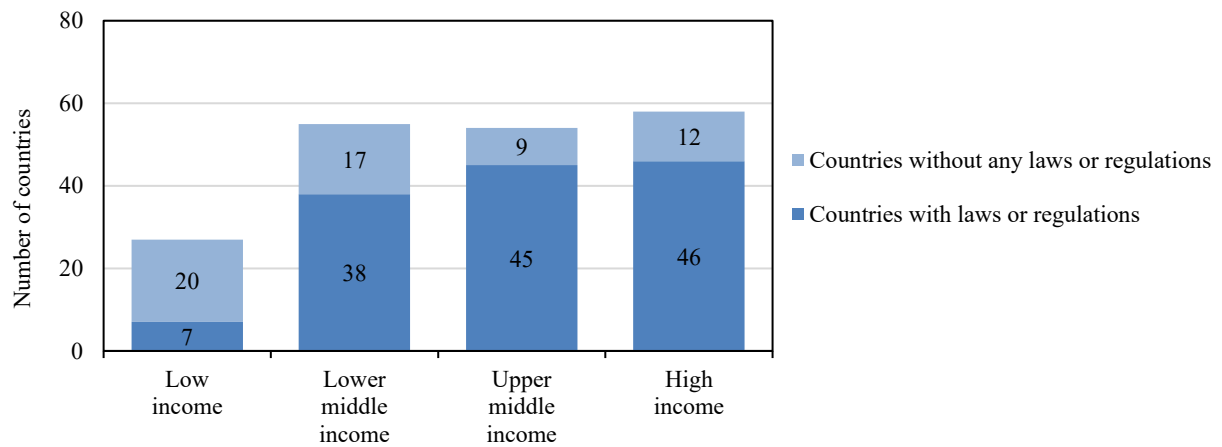


Figure 3.23 Breakdown of 194 countries on the establishment status of legal and regulatory frameworks for each level of economic development of countries

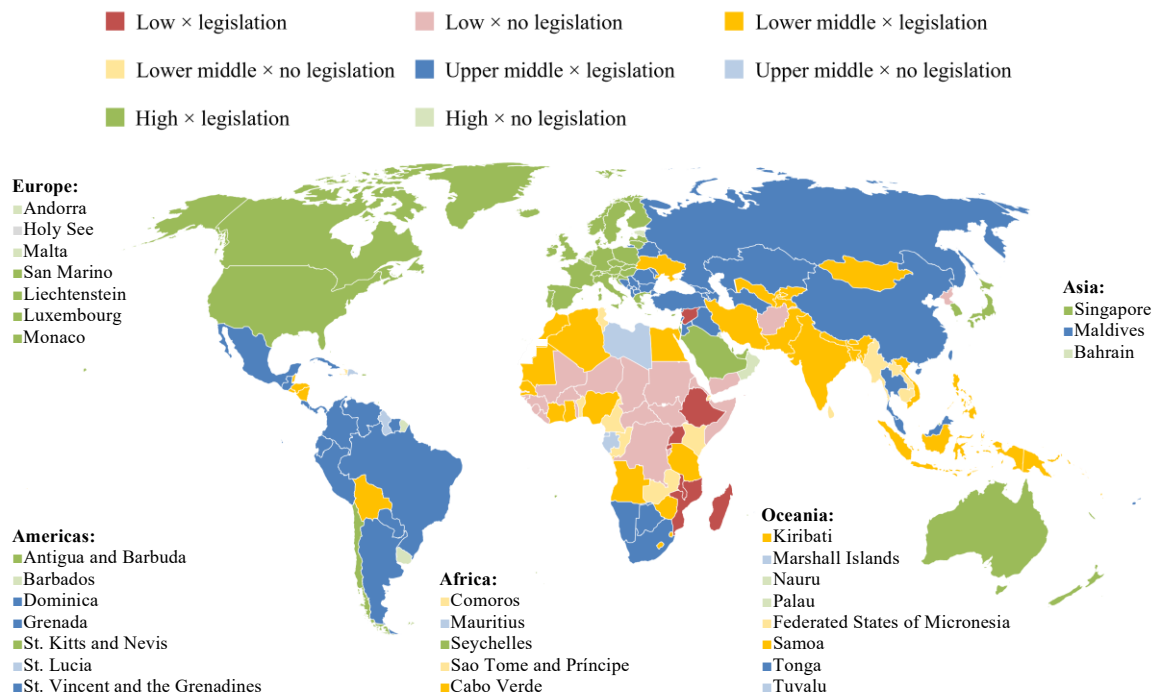


Figure 3.24 Distribution of the establishment status of legal and regulatory frameworks for each level of economic development of countries in 194 countries

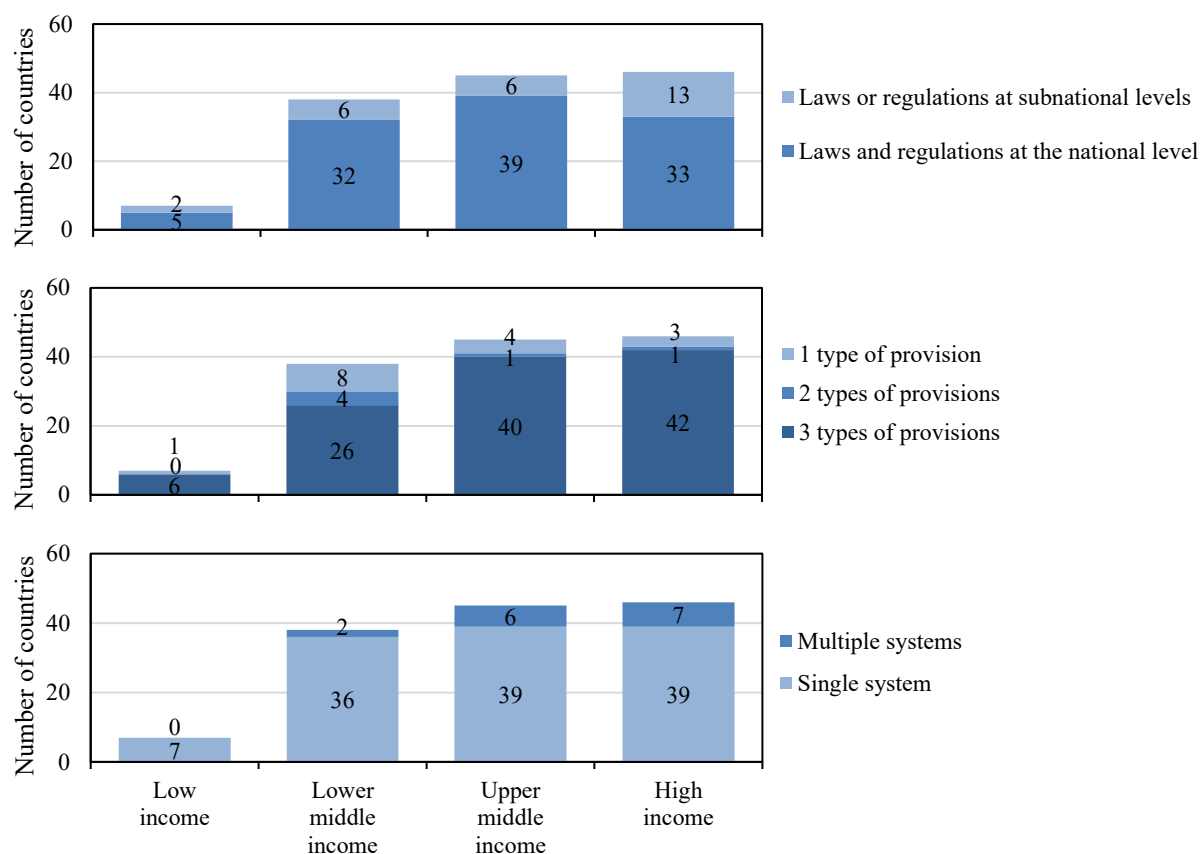


Figure 3.25 Breakdown of 137 countries establishing national or subnational legislation, defining one to three types of provisions, or accepting single or multiple systems for each level of economic development of countries

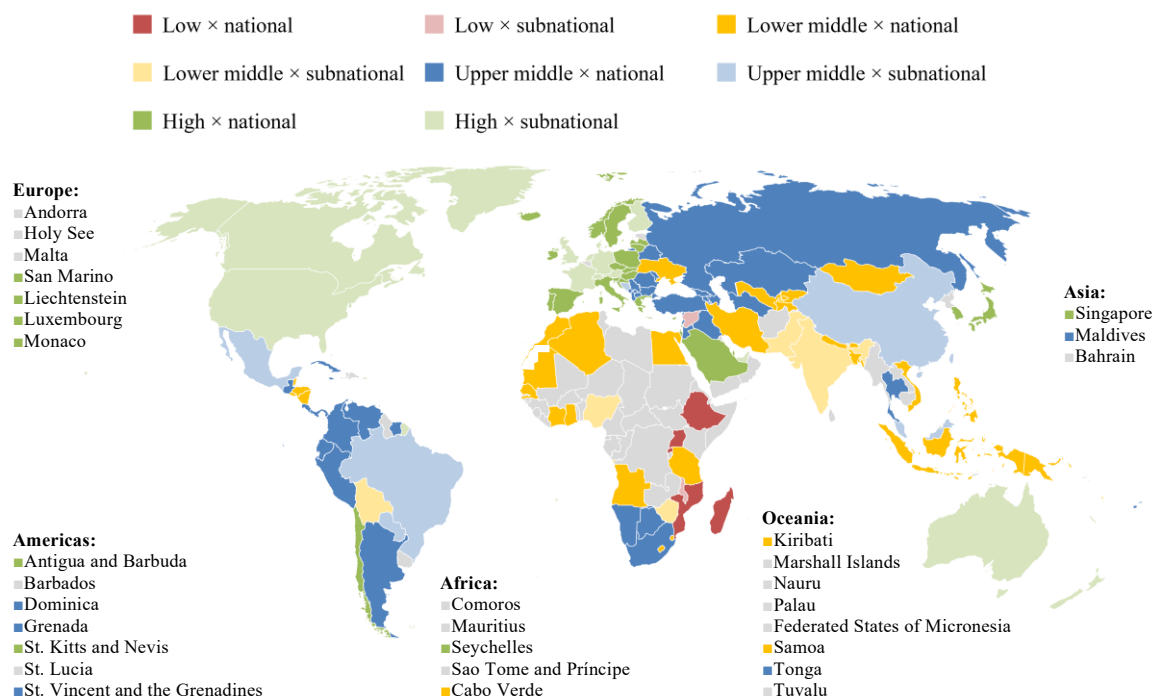


Figure 3.26 Distribution of national or subnational legislation for each level of economic development of countries in 137 countries

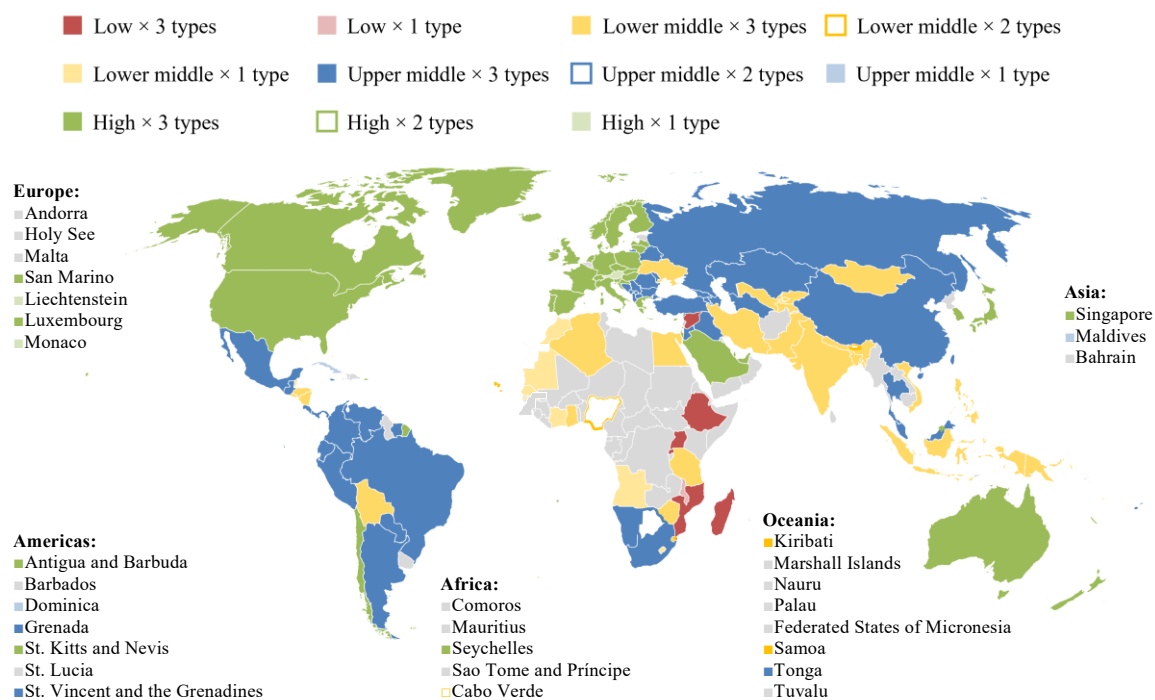


Figure 3.27 Distribution of one to three types of provisions for each level of economic development of countries in 137 countries

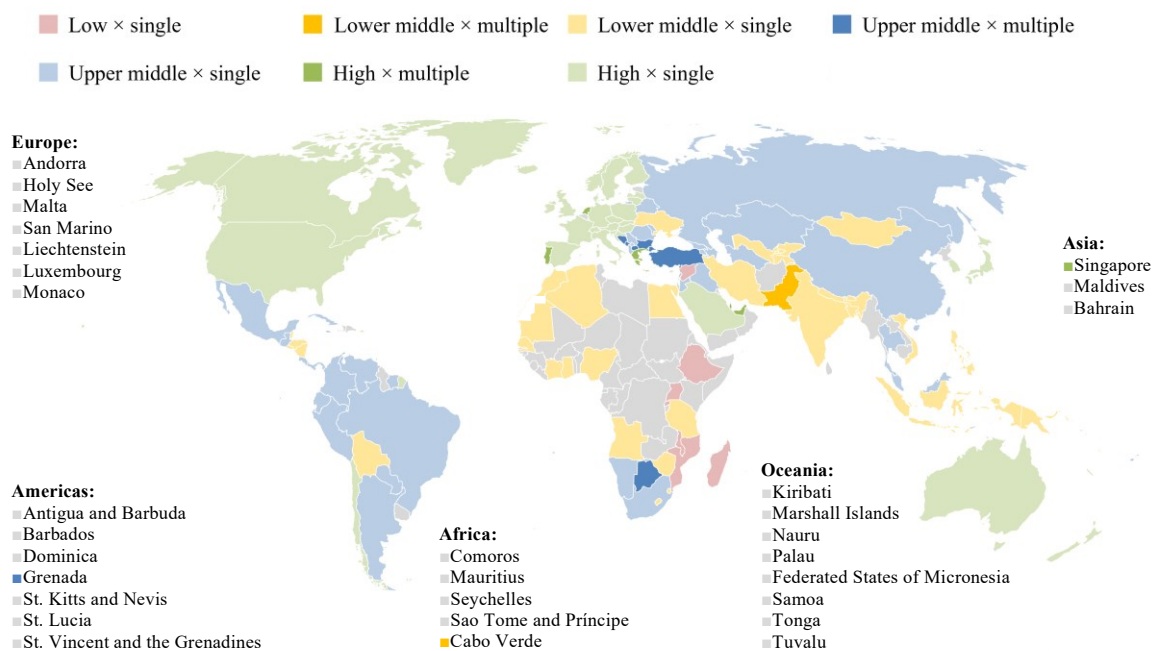


Figure 3.28 Distribution of single or multiple systems for each level of economic development of countries in 137 countries

3.5 National or Subnational Initiatives

National or subnational initiatives should indicate the potential future establishment of legal and regulatory frameworks. We discuss states of progress toward legislation and a future worldwide picture through some initiatives for the 58 countries.

58 countries whose legal and regulatory framework was not identified are roughly divided into four groups of countries with: 1) no architectural requirements, 2) no structural safety requirements, 3) no wind-resistant safety requirements, and 4) no accessible information, according to their current legal and regulatory situations. The first group does not define any wind-resistant safety requirements within the legal and regulatory framework. The second group does not define either any structural safety requirements or any wind-resistant safety requirements, within the legal and regulatory framework. The third group does not define even architectural requirements, let alone any structural safety requirements and any wind-resistant safety requirements, within the legal and regulatory framework. The fourth group indicates that no information about the first to third groups above was available for this study. Additionally, the breakdown of 58 countries is 30, 7, 11, 4, and 6 countries in Africa, the Americas, Asia, Europe, and Oceania, respectively.

Table 3.16 shows current legal and regulatory scopes and efforts towards improving them. The numerical value in parentheses: () shows the number of countries. The first group consists of seven countries. Of these, two countries: Palau and Nauru have a high potential for establishing the legal and regulatory framework, which requires codes or standards for wind-resistant safety requirements. Three countries: Somalia, Barbados, and Timor-Leste have not shown a way forward to passing relevant bills. In two countries with their own initiatives: Haiti and Afghanistan, no concrete efforts were identified in this study. The second group consists of 27 countries. Of these, five countries: Kenya, Myanmar, Malta, the Federated States of Micronesia, and Marshall Islands plan to enforce regulations including not only structural safety requirements but also wind-resistant safety requirements within their own legal and regulatory framework. Two countries: St. Lucia and Laos have long held this challenge pending. In 20 countries: Burundi, Comoros, Djibouti, Mauritius, Cameroon, Chad, Congo-Brazzaville, Congo-Kinshasa, Gabon, Tunisia, Benin, Burkina Faso, Guinea-Conakry, Togo, North Korea, Uruguay, Cambodia, Bahrain, Kuwait, and Tuvalu, no national or subnational initiatives were identified in this study. The third group consists of 13 countries. Of these, three countries: Dominican Republic, Guyana, and Solomon Islands plan to enforce regulations including wind-resistant safety requirements. One country: Sierra Leone has not yet expressed its intention to approve the relevant bill. Concrete efforts in line with ongoing initiatives in one country: Sri Lanka, as well as national or subnational initiatives in eight countries: Zambia, Sao Tome and Principe, Trinidad and Tobago, Oman, Yemen, Estonia, Andorra, and Belgium were not identified in this study. The fourth group consists of 11 countries in Africa. In these countries, neither information about existing law or regulations nor efforts toward their establishment were accessible for this study.

As described above, at least 10 countries: Dominican Republic, Guyana, Solomon Islands, Kenya, Myanmar, Malta, the Federated States of Micronesia, Marshall Islands, Palau, and Nauru are taking

initiatives to establish a legal and regulatory framework including wind-resistant safety requirements. In any case, the number of countries with a legal and regulatory framework should not increase dramatically but rather gradually. From a worldwide perspective, national or subnational initiatives in Africa, where quite a few countries have not established any legal and regulatory framework, should be particularly paid attention to for a while.

Figure 3.29 shows Table 3.16 on the world map. Here, for example, “3-ongoing” denotes that “Current legal and regulatory scope” covers “architectural and structural safety requirements” but does not step into “wind-resistant safety requirements”, and “Effort toward improving the scope” is currently “ongoing”. Also, this figure individually shows the status of 30 small countries with less than 5,000 km². This figure shows that most countries without accessible information are African countries, unfamiliar to Japan. Obtaining information from these countries will be a future task.

Table 3.16 Current legal and regulatory scopes and efforts toward improving them in 58 countries

Current legal and regulatory scope		Country	Effort toward improving the scope
1	No architectural requirements (7)	Palau, Nauru (2)	ongoing
		Somalia, Barbados, Timor-Leste (3)	pending
		Haiti, Afghanistan (2)	unclear
2	No structural safety requirements (27)	Kenya, Myanmar, Malta, Federated States of Micronesia, Marshall Islands (5)	ongoing
		St. Lucia, Laos (2)	pending
		Burundi, Comoros, Djibouti, Mauritius, Cameroon, Chad, Congo-Brazzaville, Congo-Kinshasa, Gabon, Tunisia, Benin, Burkina Faso, Guinea-Conakry, Togo, Uruguay, North Korea, Cambodia, Bahrain, Kuwait, Tuvalu (20)	unclear
3	No wind-resistant safety requirements (13)	Dominican Republic, Guyana, Solomon Islands (3)	ongoing
		Sierra Leone (1)	pending
		Zambia, Sao Tome and Principe, Trinidad and Tobago, Sri Lanka, Oman, Yemen, Estonia, Andorra, Belgium (9)	unclear
4	No accessible information (11)	Eritrea, South Sudan, Central African Republic, Equatorial Guinea, Libya, Sudan, Gambia, Guinea-Bissau, Liberia, Mali, Niger (11)	-

Note: the numerical value in parentheses: () shows the number of countries.

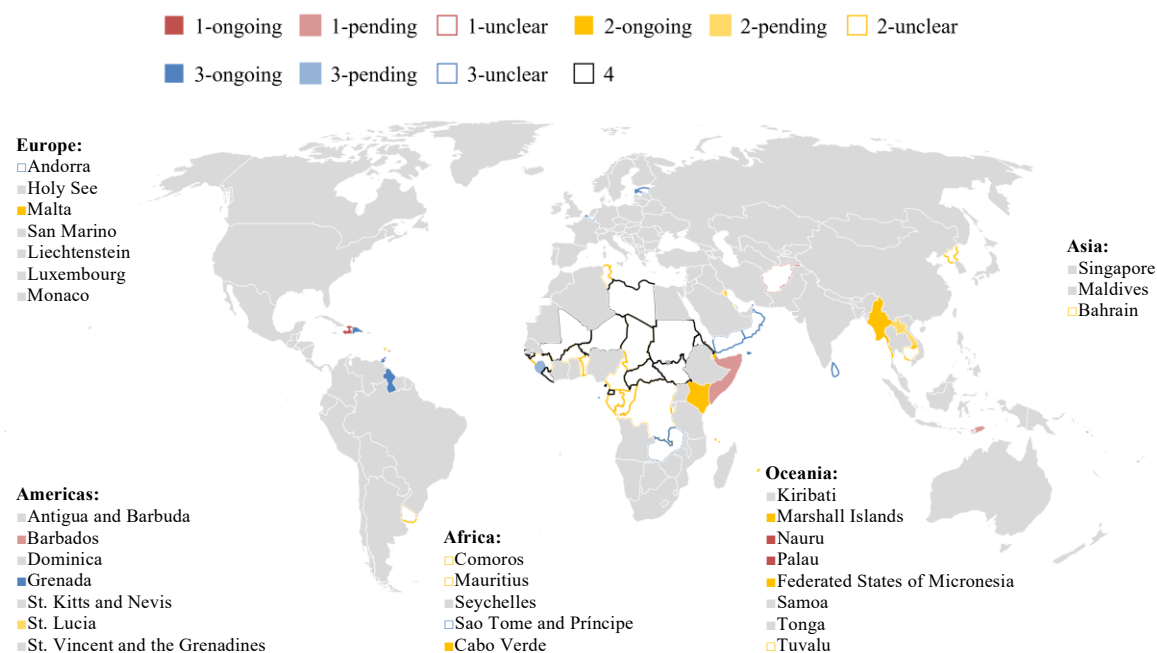


Figure 3.29 Distribution of current legal and regulatory scopes and efforts toward improving them in 58 countries

3.6 Conclusions

This chapter discussed the worldwide status on legal and regulatory frameworks in 137 countries, accounting for 70% of the total, focusing on three types of provisions: wind-resistant design liability, wind load calculation methods, and reference wind speeds or pressures. First, we studied the current worldwide status for each type of provision, and then analyzed the status from two perspectives: jurisdictions and requirements. Next, we examined worldwide challenges in establishing legal and regulatory frameworks from three perspectives: human or economic damage from storms, and economic developments of countries. Finally, we discussed the future status on legal and regulatory frameworks based on national or subnational initiatives in the remaining 58 countries that currently lack them. The results are summarized as follows

(1) Worldwide status on legal and regulatory frameworks

- 137 countries, accounting for 70% of the total, at least mention or imply wind-resistant design liability within legal and regulatory frameworks. Of these, 121 and 115 countries, accounting for 62% and 59% of the total, also define wind load calculation methods and reference wind speeds or pressures therein, respectively.
- 110 and 27 countries, accounting for 56% and 14 % of the total, mention or imply wind-resistant design liability at the national and subnational levels, respectively.
- 16 countries mention or imply only wind-resistant design liability, and another set of 16 countries accept multiple systems in either wind load calculation methods or reference wind speeds or pressures. Both account for 8.2% of the total.

(2) Human damage from storms

- No or small loss areas spread across Africa and Europe. Large loss areas extend to the Americas and Asia with tropical cyclone areas.
- The level of maximum human damage from storms is not always a decisive factor, but it does have some influence on the establishment of laws or regulations related to wind-resistant design of buildings.
- The number of countries establishing laws or regulations at the national level is approximately the same regardless of human damage level. However, the number of countries establishing laws or regulations at subnational levels increases with the rise of human damage level.

(3) Economic damage from storms

- No/low loss areas spread across Africa. Extreme loss areas extend not only to the Americas and Asia with tropical cyclone areas but also to Europe.
- Economic damage from storms does not necessarily directly lead to the establishment of laws or regulations.

(4) Economic development of countries

- Low income areas spread across Africa. High income areas extend to Europe.
- The establishment of laws or regulations requires at least the level of lower middle income. Additionally, more financial or technical support for lower middle income countries, which define only wind-resistant design liability, is highly effective for the full establishment of laws or regulations.
- Countries with higher economic development levels can establish laws or regulations at subnational levels or accept multiple systems.

(5) National or subnational initiatives

- The number of countries with legal and regulatory frameworks should continue to increase gradually rather than dramatically. At least 10 countries, accounting for 5.1% of the total, are taking initiatives to establish a legal and regulatory framework including wind-resistant safety requirements.

This chapter contributed to a specific objective of this thesis: revealing the worldwide status on legal and regulatory frameworks, including provisions on wind-resistant design of buildings, and discussing challenges in establishing them.

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4 WORLDWIDE TRENDS OF CODES AND STANDARDS

In this chapter, we discuss worldwide trends of 176 codes and standards in 190 countries, accounting for 97% of the total, to compile an overall picture of codes and standards worldwide from the perspective of atmospheric boundary layer models. First, we review atmospheric boundary layer models as engineering models for categorizing codes and standards. Next, we define classification categories and classify the models accepted in each country. Then, we study the current worldwide trends of 176 codes and standards based on the classified models. Furthermore, we discuss the future trends of some predominant models from regional or national initiatives in regions or countries in transition phases. Five untargeted countries are Eritrea, South Sudan, Sudan, and Gambia in Africa, and Yemen in Asia, where no authentic or complete information was available.

For countries where current information was not available for this study, it should be noted that information available prior to the initiation of this study in 2011 is included in the analysis of the 176 codes and standards.

Relevant conference paper:

- Hayakawa, A., Matsui, M., and Tamura, Y. 2017. “Popular Trend of Wind Loading Codes and Standards in the World. [Japanese]”, Summaries of Technical Papers of Annual Meeting, AIJ, Chugoku, Japan, August 2017, No. 20087, pp.73-74.

4.1 Engineering Models for Categorization

Codes or standards related to wind-resistant design of buildings have various origins. Most internationally recognized codes or standards were developed based on research findings obtained in respective countries. Otherwise, codes or standards were developed by combining codes or standards from respective countries with those from other countries, or by combining only codes or standards from other countries. Therefore, worldwide trends regarding codes and standards vary depending on which process in the wind load calculation flow is focused on. Considering that one of the final goals of this study is to reveal differences in reference wind speeds in national border areas, it is more practical to focus on turbulence spectrum than on anything else, because it forms a base for statistically converting averaging times of wind speeds. However, considering specifications of reference wind speeds likely to differ from country to country, assuming comparisons through design wind speeds in national border areas, this section reviews reference wind speed, wind speed profile, and turbulence characteristics, which describe atmospheric boundary layers.

4.1.1 Reference wind speed

Reference wind speed U_{ref} (m/s) is defined as the wind speed in the u-direction averaged over any period, referenced to any height over any terrain roughness, for any probability of exceedance in one year. The World Meteorological Organization (WMO) defines U_{ref} as shown in Table 4.1.

(1) Averaging time

U_{ref} should be representative of the situation at a specific construction site of buildings, which can be achieved by choosing a sufficiently homogeneous and stationary averaging time. According to investigations into turbulence of near-ground wind speeds, energy spectra have two separate harmonic contents, as shown in Figure 4.1. (van der Hoven 1957) The first represents synoptic scale meteorology with periods ranging from approximately 1 hour to several months. The second represents microscale meteorology with periods ranging from a few seconds to approximately 10 minutes. These contents are separated by a frequency range that is almost free of harmonic contents, designated as a spectral gap, with periods ranging from around 10 minutes to 1 hour. The likely presence of a spectral gap at or near hourly averaged wind speeds has resulted in its broad adoption as a sampling length of choice for statistical studies of smaller scale near-ground atmospheric turbulence. However, as more homogeneous data have become available over time, it has become increasingly clear that the large energy gap first identified by Van der Hoven is simply not as great as suggested in Figure 4.1 and may typically only be about a factor of two lower than the higher frequency peak energy level. (WMO 2010)

In practical use, for synoptic storms, a 1-hour averaging time is commonly chosen as the sampling length. For tropical cyclone storms, a slightly shorter averaging time down to about 10 minutes is desirable to avoid non-stationarity of the phenomena of interest. For thunderstorm downbursts or tornadoes, more suitably downscaled mean wind averaging times like 3 seconds or less are required, because they are even more transient atmospheric events. (WMO 2010)

(2) Height and level

U_{ref} is provided in the form of a numerical value, contour map, or zoning map at a specific height above ground or sea level.

(3) Terrain roughness

Terrain roughness represents characteristics of the ground surface irregularities. The International Organization for Standardization (ISO) standard (ISO 2009) divides it into four categories as shown in Table 4.2 and Figure 4.2. Category 1 is defined as “Open sea flat surface”, which represents the open sea or lakes, or unobstructed coastal areas on land. Category 2 is defined as “Open country”, which represents a ground with well-scattered obstructions. Category 3 is defined as “Suburban”, which represents a ground with numerous closely spaced obstructions. Category 4 is defined as “Urban”, which represents a ground with numerous large, high, and closely spaced obstructions.

(4) Return period

Occurrence frequencies are considered as a factor related to the design philosophy. Two periods are commonly considered in structural design. One is a return period, and the other is a usable lifetime. The former is the mean time interval of events where the intensity of loads exceeds a specific load. The latter is the design working life, which is the period during which a building is expected to be maintained as planned without major repairs to fulfill its original usage.

(5) Air density

Reference velocity pressure q_{ref} (N/m²) is provided in some codes or standards in place of U_{ref} . q_{ref} is converted into U_{ref} by the following expression,

$$U_{ref} = \sqrt{2q_{ref}/\rho}, \quad (4.1)$$

where ρ (kg/m³): air density.

Table 4.1 Definition of reference wind speeds in WMO

Factor	Definition
Averaging time	10 minutes
Height and level	10 meters above the ground
Terrain roughness	open terrain (an area where the distance between the anemometer and any obstruction is at least 10 times but preferably 20 times the height of the obstruction)

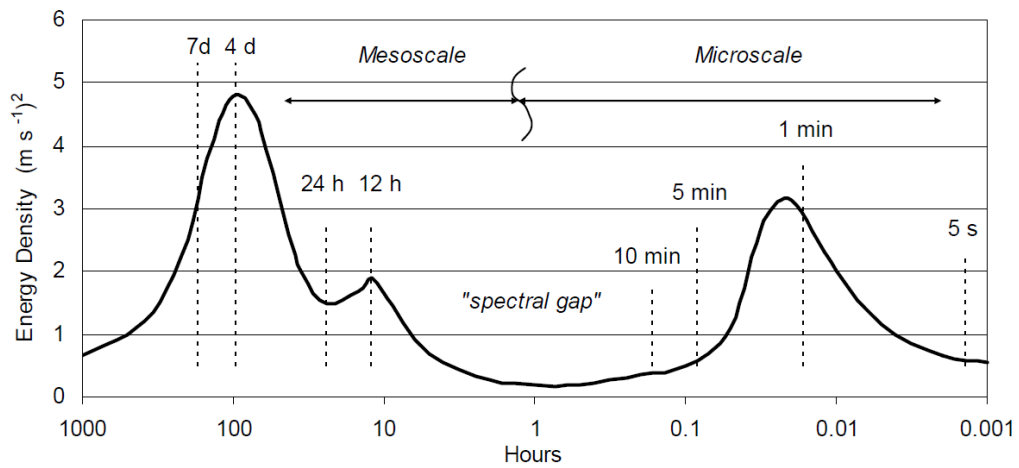


Figure 4.1 Schematic energy spectrum of near-ground wind speed

Table 4.2 Roughness length and power law exponent in ISO

Terrain roughness category		z_0 (m)	ε		
			3 sec.	10 min.	1 hr.
1	Open sea flat surface	0.003	0.074	0.113	0.120
2	Open country	0.03	0.103	0.147	0.154
3	Suburban	0.3	0.152	0.214	0.220
4	Urban	3.0	0.256	0.403	0.428

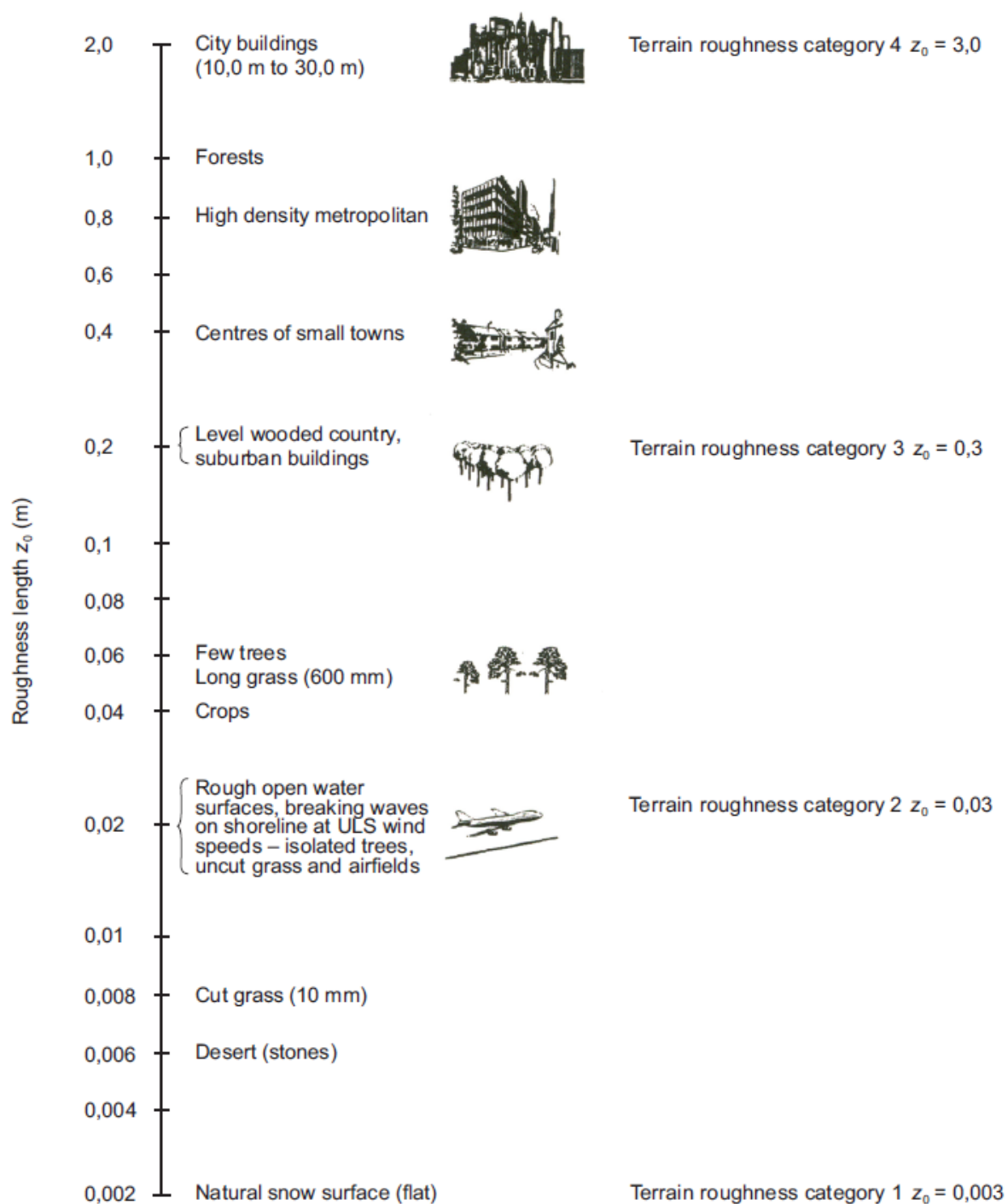


Figure 4.2 Relations between roughness length and terrain roughness category

4.1.2 Wind speed profile

Wind speed profile $K_u(z)$, which is commonly called as exposure factor, is a measure of the magnitude of mean wind speed components in the u-direction relative to U_{ref} . Here, z (m) denotes a height above ground. $K_u(z)$ differs at the same height in accordance with averaging time of U_{ref} . Synoptic storm hourly mean wind speed $\bar{U}(z)$ (m/s) is defined to fit roughness length z_0 (m) by the following relationships (Harris and Deaves 1980).

$$\frac{\bar{U}(z)}{u_*} = 2.5 \left[\ln \left(\frac{z}{z_0} \right) + 5.75 \left(\frac{z}{z_G} \right) - 1.875 \left(\frac{z}{z_G} \right)^2 - 1.333 \left(\frac{z}{z_G} \right)^3 + 0.25 \left(\frac{z}{z_G} \right)^4 \right], \quad (4.2)$$

$$z_G = \frac{u_*}{6f}, \quad (4.3)$$

$$f = 2\Omega \sin \phi, \quad (4.4)$$

where z_G (m): gradient height, ϕ (degrees): latitude, Ω : angular velocity of the Earth's rotation (72.9×10^{-6} radians/s), and u_* (m/s): frictional velocity. Ignoring second-order terms, the above relationships reduce to

$$\frac{\bar{U}(z)}{u_*} = 2.5 \left[\ln \left(\frac{z}{z_0} \right) + 34.5 \left(\frac{fz}{u_*} \right) \right], \quad (4.5)$$

which can be used up to $z=300$ with little error, compared with values given by the above relationships which can apply up to $z=z_G$. It follows that $K_u(z)$ is closely approximated by

$$K_u(z) = \frac{\bar{U}(z)}{\bar{U}(10)} = \frac{\ln(z/z_0) + 34.5(fz/u_*)}{\ln(10/z_0)}. \quad (4.6)$$

Table 4.2 also shows z_0 and ε in $\bar{U}(z_G)=50$ and latitude $\phi=40$ when $K_u(z)$ is expressed with logarithmic law relationship: $k_l \ln(z/z_0)$ and power law relationship: $k_p(z/10)^\varepsilon$.

4.1.3 Turbulence characteristics

(1) Turbulence intensity profile

Turbulence intensity profile $I_u(z)$ is a measure of the magnitude of fluctuating wind speed components in the u-direction $u(z, t)$ relative to $U_{ref} K_u(z)$. Here, t (s) denotes a time. $I_u(z)$ differs at the same height in accordance with the averaging time of U_{ref} . Where terrain roughness is uniform upwind of the site for at least 30 km, $I_u(z)$ is given by the following expression (Harris and Deaves 1980).

$$I_u(z) = \frac{\sigma_u(z)}{u_*} \frac{u_*}{\bar{U}(z)}, \frac{\sigma_u(z)}{u_*} = \frac{7.5\eta \left[0.538 + 0.09 \ln \left(\frac{z}{z_0} \right) \right]^{\eta^{16}}}{1 + 0.156 \ln \left(\frac{u_*}{fz_0} \right)}. \quad (4.7)$$

where $\sigma_u(z)$: standard deviation of $u(z, t)$.

(2) Turbulence spectrum

Turbulence spectrum $S_u(z, n)$, which is known as a spectral density function, is a measure of the magnitude of $u(z, t)$ at each frequency n (Hz). $S_u(z, n)$ is defined as the Fourier transform of the auto-correlation function of $u(z, t)$. In wind engineering, some mathematical forms for $S_u(z, n)$ have been proposed and have the common non-dimensional form as below:

$$\frac{nS_u(z, n)}{u_*^2} = \frac{aN_u(z)^\gamma}{(b + cN_u(z)^\alpha)^\beta}, \quad (4.8)$$

$$N_u(z) = \frac{nL_u(z)}{U(z)}, \quad (4.9)$$

where a , b , and c : position factors, α , β , and γ : shape factors, $N_u(z)$: non-dimensional frequency, and $L_u(z)$ (m): turbulence scale profile. $L_u(z)$ determines the peak frequency of $S_u(z, f)$. There are two types of formulae describing $S_u(z, n)$: height independent and dependent ones. The first type has two representative turbulence spectra: Davenport (1961) and Harris (1970), and the second type has three representative turbulence spectra: Karman (Harris 1968; Von Karman 1948), Kaimal (Kaimal et al. 1972), and Simiu (1974). Table 4.3 shows a , b , c , α , β , γ , $L_u(z)$, and $U(z)$ in these five representatives. Of these, the Davenport and Harris spectra define the characteristic scales at 10 m above ground as $L_u(z)$.

It should be noted that the following normalized one-sided power spectrum density function, based on the Kolmogorov -5/3 spectrum, provides a very good approximation in the high frequency range. (Shiotani 1979)

$$\frac{nS_u(z, n)}{u_*^2} = AN_z^{-\frac{2}{3}}(z), \quad (4.10)$$

where A : constant. The Davenport spectrum is a modification of the Kolmogorov spectrum in the inertial range of turbulence to account for low-frequency behavior. Although there is no evidence for the behavior on the lower frequency than that at the spectral peak, it has been successfully applied in wind speed modeling.

(3) Turbulence scale profile

Turbulence scale profile $L_u(z)$, which is known as an integral scale, is a measure of the size of spatial spread of $u(z, t)$. $L_u(z)$ is defined as the integration of the zero-lag cross-correlation coefficient of $u(z, t)$ at two different points: p_1 and p_2 , ${}_{12}\rho_u(z, r)$, with respect to separation distance r (m), as in

$$L_u(z) = \int_0^\infty {}_{12}\rho_u(z, r) dr. \quad (4.11)$$

In wind engineering, ${}_{12}\rho_u(z, r)$ is commonly approximated by the following exponential expression (Townsend 1976):

$${}_{12}\rho_u(z, r) = \exp\left(-\frac{r}{L_u(z)}\right). \quad (4.12)$$

In this case, the distance r is $L_u(z)$ when ${}_{12}\rho_u(z, r)$ is $1/e$.

(4) Turbulence coherence

Turbulence coherence $Coh_u(n, {}_{12}r)$ is a measure of the frequency-dependent spatial correlation of $u(z, t)$ between two different points: p1 and p2. Here, ${}_{12}r$ (m) denotes the distance between p1 and p2. $Coh_u(n, {}_{12}r)$ is defined as the Fourier transform of the cross-correlation function of $u(z, t)$ at p1 and p2. In wind engineering, the square root of $Coh_u(n, {}_{12}r)$ is commonly approximated by the following exponential expression (Davenport 1961):

$$\sqrt{Coh_u(n, {}_{12}r)} = \exp\left(-k \frac{n {}_{12}r}{{}_{12}\bar{U}(z)}\right), \quad (4.13)$$

where, k : decay factor, which reflects the degree of spatial correlation of wind speed, and ${}_{12}\bar{U}(z)$: u-direction wind speed averaged at p1 and p2. k is assumed to be between 5 and 8. (Davenport 1967)

Table 4.3 Specifications of representative spectral density functions

Type	Spectrum	a	b	c	α	β	γ	$L_u(z)$	$U(z)$
Height independent	Davenport	4	1	1	2	4/3	2	1,200	$U(10)$
	Harris	4	2	1	2	5/6	1	1,800	$U(10)$
Height dependent	Karman	24	1	70.78	2	5/6	1	$L_u(z)$	$U(z)$
	Kaimal	105	1	33	1	5/3	1	z	$U(z)$
	Simiu	200	1	50	1	5/3	1	z	$U(z)$

4.2 Category Classification

Many developed countries, as well as some international organizations, develop codes or standards related to wind-resistant design of buildings. On the other hand, most developing countries adopt them due to historically or geopolitically deep relationships without change, or develop their own codes or standards using examples from them without giving much consideration to differences such as meteorological conditions. Therefore, it is meaningful to understand worldwide trends of codes and standards from the perspective of their country of origin. In this chapter, worldwide trends of codes and standards are studied from three components of the atmospheric boundary layer models: wind speed profile, turbulence intensity profile, and turbulence spectrum with turbulence scale profile.

4.2.1 Category settings

Atmospheric boundary layer models are classified into three categories: Worldwide (WW), Regional (RG), and Domestic (DS) models based on their extent of spread to other regions or countries. Worldwide (WW) models are accepted in multiple regions including Africa, the Americas, Asia, Europe, and Oceania. Regional (RG) models are only accepted in individual regions such as Africa, the Americas, Asia, Europe, or Oceania. Domestic (DS) models are only accepted in the country of origin. Furthermore, the models are classified based on their country or international organization of origin into 22 subcategories: Australian (AU), Bajan (BD), Brazilian (BR), Canadian (CA), Dutch (NL), European Union (EU), French (FR), German (DE), Indian (IN), International Organization for Standardization (IO), Italian (IT), Japanese (JP), Mexican (MX), Peruvian (PE), Portuguese (PT), Russian (RU), South African (ZA), Swiss (CH), United Kingdom (UK), United States (US), Former Yugoslavian (YU), and Domestic (DS) models.

It should be noted that some codes or standards, for which information on the models could not be identified in this study or which do not define the models, are grouped together as Unclassifiable (UC) models.

Each category or subcategory is described from the following four perspectives:

- what subcategories make up each category,
- how many sets of models are in each subcategory,
- in which regions or countries the sets of models in each subcategory are accepted, and
- which sets of models are defined.

Table 4.4 shows some situations from the first to third perspectives. The numerical value in parentheses: () shows the number of atmospheric boundary layer models. Table 4.5 shows codes or standards in the Domestic (DS) models.

(1) Worldwide (WW) models

This category consists of 12 subcategories: Australian (AU), Bajan (BD), Canadian (CA), Dutch (NL), European Union (EU), French (FR), German (DE), International Organization for Standardization (IO), Portuguese (PT), Russian (RU), United Kingdom (UK), and United States (US) models.

1) Australian (AU) models

This subcategory consists of two sets of models for Australia and one set of models for Australia and New Zealand, which are defined in AS 1170.2'81, AS 1170.2'89, AS/NZS 1170.2'02, and AS/NZS 1170.2'11. Of these, AS/NZS 1170.2'02 and AS/NZS 1170.2'11 are exactly the same model. All or part of these models is accepted even in Asian and other Oceanian countries.

2) Bajan (BD) model

This subcategory consists of one set of models for Barbados, which is defined in BNS CP 28'81, BNS DPC'10, and BNS TR 28'13. These models, which are combined with BS CP3 CV2'72 and the draft edition of ANSI A58.1'82, are exactly the same model. These models are accepted even in other American countries and overseas territories of the United Kingdom.

3) Canadian (CA) model

This subcategory consists of one set of models for Canada, which is defined in NBCCA'05, NBCCA'10, and NBCCA'15. NBCCA'10 and NBCCA'15 are exactly the same model, which is only one less terrain roughness category than NBCCA'05. NBCCA'05 and NBCCA'10 define only one component: wind speed profile, and UG-NBCCA'06 (NRC 2006) and UG-NBCCA'11 can supplement the remaining two components: turbulence intensity profile and turbulence spectrum, respectively. All or part of these models is accepted even in Asian countries.

4) Dutch (NL) models

This subcategory consists of two sets of models for the Netherlands, which are defined in NEN 6702'07 and NEN EN NA'11, and two sets of models for Aruba and Suriname, which are defined in OWAW'81 and BB1'56, respectively. OWAW'81 defines only two components: wind speed profile and turbulence intensity profile. BB1'56, which was enacted before independence, defines only one component: velocity pressure profile.

5) European Union (EU) models

This subcategory consists of two sets of models for member countries of the European Union, which are defined in ENV'95 and EN'05. EN'05 differs from ENV'95 in the definition of terrain roughness categories. All or part of these models is accepted even in African and Asian countries.

6) French (FR) models

This subcategory consists of one set of models for the metropolitan France, which is defined in NV 46'47, and two sets of models for the metropolitan France and overseas departments, which are defined in NV 65'76, NV 65'87, NV 65'00, NV 65'09, and NF EN NA'08&'12. Of these, NV 65'76 to NV 65'09 are exactly the same model. NV 46'47 and NV 65'76 to NV 65'09, which define only one component: wind speed profile, are accepted even in African countries, Lebanon, and Monaco.

7) German (DE) models

This subcategory consists of two sets of models for Germany, which are defined in DIN 1055-4'86 and DIN EN NA'10. DIN 1055-4'86, which defines only one component: wind speed profile, is accepted in Turkey.

8) International Organization for Standardization (IO) model

This subcategory consists of one set of models, which is defined in the International Organization for Standardization standard: ISO 4354'97. This model, which defines only two components: wind speed profile and turbulence intensity profile, is accepted in American and European countries.

9) Portuguese (PT) models

This subcategory consists of three sets of models for Portugal, which are defined in RSEP'61, RSA'83, and NP EN NA'10. RSEP'61 and RSA'83, which define only one component: wind speed profile, are accepted even in African countries.

10) Russian (RU) models

This subcategory consists of two sets of models for the former Soviet Union countries and Russia, which are defined in SNIp 2.01.07'88, SNIp 2.01.07'05, SP 20.13330'11, SP 20.1325800'14, and SP 20.13330'16. Of these, SNIp 2.01.07'88 to SP 20.13330'11 and SP 20.13330'16 define exactly the same model. All models define only one component: wind speed profile, and TsNIISK'00 can supplement the remaining two components: turbulence intensity profile and turbulence spectrum. All or part of these models is accepted even in Mongolia and Bulgaria.

11) United Kingdom (UK) models

This subcategory consists of four sets of models for the United Kingdom and the Crown Dependency, which are defined in BS CP3 CV'52, BS CP3 CV2'70, BS CP3 CV2'72, BS 6399.2'97, and BS EN NA'10. Of these, BS CP3 CV2'70 and BS CP3 CV2'72 are exactly the same model. BS 6399.2'97 defines only two components: wind speed profile and turbulence intensity profile, and BS CP3 CV'52 to BS CP3 CV2'72 define only one component: wind speed profile. All or part of these models is accepted not only in African and Asian countries but also Guyana and Samoa.

12) United States (US) models

This subcategory consists of three sets of models for the United States and unincorporated territories, which are defined in UBC'64, ANSI A58.1'82, ASCE 7'88, UBC'88, UBC'97, ASCE 7'98, ASCE 7'02, IBC'03, ASCE 7'05, IBC'06, IBC'09, ASCE 7'10, IBC'12, IBC'15, ASCE 7'16, and IBC'18. The breakdown of the three sets is UBC'64, ANSI A58.1'82 to UBC'97, and ASCE 7'98 to IBC'18. Of these, the models of UBC'88 and UBC'97 have gust factors built into the exact same model of ANSI A58.1'82 and ASCE 7'88. ASCE'02 to IBC'18, which are only one less terrain roughness category than ASCE 7'98, define exactly the same model. ASCE 7'02, ASCE 7'05, ASCE 7'10, and ASCE 7'16 are responsible for the models of IBC'03, IBC'06 and IBC'09, IBC'12 and IBC'15, and

IBC'18, respectively. The source of UBC'64 is the national standard: ANSI A58.1'55. ANSI A58.1'82 and ASCE 7'88 defines only two components: wind speed profile and turbulence intensity profile. UBC'64, UBC'88, and UBC'97 define only one component: wind speed profile. ANSI A58.1'82 and ASCE 7'88, as well as some references listed therein, can supplement two components: turbulence intensity profile and turbulence spectrum unstated in UBC'88 and UBC'97. All or part of these models is accepted not only in African, American, Asian, and Oceanian countries but also overseas territories of the Netherlands and the United Kingdom.

(2) Regional (RG) models

This category consists of nine subcategories: Brazilian (BR), Indian (IN), Italian (IT), Japanese (JP), Mexican (MX), Peruvian (PE), South African (ZA), Swiss (CH), and Former Yugoslavian (YU) models.

1) Brazilian (BR) model

This subcategory consists of one set of models for Brazil, which is defined in NBR 6123'88 and NBR 6123'13. These models are the exact same model, which defines only one component: wind speed profile. The underlying dissertation (Galindez 1979) can supplement the remaining two components: turbulence intensity profile and turbulence spectrum. Some definitions of NBR 6123'88 are accepted in Paraguay.

2) Indian (IN) models

This subcategory consists of two sets of models for India, which are defined in IS 875.3'87, NBCIN'05, IS 875.3'15, and NBCIN'16. IS 875.3'87 and NBCIN'05 define exactly the same model, and the relationship of IS 875.3'15 and NBCIN'16 is similar. NBCIN'05 and IS 875.3'87 define only two components: wind speed profile and turbulence spectrum. IS 875.3'87 is accepted even in Bhutan and Nepal.

3) Italian (IT) model

This subcategory consists of one set of models for Italy, which is defined in CNR-DT 207'08, UNI EN NA'13, and NTC'18. NTC'18 defines only two components: wind speed profile and turbulence intensity profile. UNI EN NA'13 and CNR-DT 207'08 are in the manner fully consistent with NTC'18. NTC'18 is accepted even in the Holy See and San Marino.

4) Japanese (JP) models

This subcategory consists of three sets of models for Japan, which are defined in AIJ-RLB'93, BSL-N 1454'00, and AIJ-RLB'15. BSL-N 1454'00 defines only one component: wind speed profile, and AIJ-RLB'93 can supplement the remaining two components: turbulence intensity profile and turbulence spectrum. Some definitions of AIJ-RLB'93 are accepted even in South Korea.

5) Mexican (MX) models

This subcategory consists of four sets of models for Mexico, which are defined in RCTB'75, NTCV'87,

NTCV'04, and NTCV'17. RCTB'75 defines only one component: wind speed profile. Some definitions of NTCV'87 and NTCV'04 are accepted even in El Salvador and Nicaragua, respectively.

6) Peruvian (PE) model

This subcategory consists of one set of models for Peru, which is defined in RNE'06. RNE'06 defines only one component: wind speed profile. Some definitions of RNE'06 are accepted even in Ecuador.

7) South African (ZA) models

This subcategory consists of three sets of models for South Africa, which are defined in SBR'66, SBR'70, SABS 0160'89, SANS 10160-3'10, SANS 10160-3'11, and SANS 10160-3'18. SANS 10160-3'10 to SANS 10160-3'18, which require the EU models for buildings above 100 m high, are exactly the same model. SBR'66, SBR'70, and SABS 0160'89 define only one component: wind speed profile. All or part of these models is accepted even in other African countries.

8) Swiss (CH) model

This subcategory consists of one set of models for Switzerland, which is defined in SIA 261'14, SIA D 0188'06, and SN EN NA'16. SIA 261'14 defines only one component: wind speed profile, and SIA D 0188'06 can supplement the remaining two components: turbulence intensity profile and turbulence spectrum. SN EN NA'16 serves as an index of relevant parts of SIA 261'14 and its commentary. This model is accepted even in Lichtenstein.

9) Former Yugoslavian (YU) model

This subcategory consists of one set of models for the Former Yugoslavia, which is defined in TPV'64. TPV'64 defines only one component: wind speed profile. TPV'64 has still been accepted in Bosnia and Herzegovina and Montenegro.

(3) Domestic (DS) models

This category and subcategory consist of 31 sets of models excluded from the above categories, as shown in Table 4.5. Of these, 16 codes and standards: ECP-201'12, LDVE'23, NCh 432'71, GB 50009'12, SCBWRD'14, RSAEEP'08, KDS 41 10 15'19, TCVN 2737'96, TCVN 2737'20, PN EN NA'10, DS 410'82, SFS EN NA'16, NS EN NA'09, EKS 11'19, NBN EN NA'10, and ONORM EN NA'13 define three components. Only one code: CPWEHK'19 defines two components: wind speed profile and turbulence intensity profile. Fourteen codes and standards: SDGUG'05, NBCNG'06, NCP 001-3'73, NC 285'03, RAVE'80, UNIT 50-84'94, RSAEEP'96, MNS 3177'81, SNI 03-1727'89, BCAR6'84, ISIRI 519'96, BCSY'12, KTP 7'78, and BLR'45 define only one component: wind speed profile.

The DS models have been developed in 25 countries without Oceanian countries. Of these, multiple DS models are accepted in three countries: Nigeria, China, and Vietnam. The parallel use with the WW and RG models is also accepted in 11 countries: Dominican Republic, Chile, Mongolia, Indonesia, Thailand, Vietnam, Iran, Syria, Denmark (Greenland), Albania, and Greece.

(4) Unclassifiable (UC) models

Three codes and standards: BSSKP'ND, BCLA'16, and TNO'88, which are adopted in any of the four countries: North Korea, Laos, Bosnia and Herzegovina, and Montenegro, have not succeeded in being classified into any model. Of these, some information obtained about BSSKP'ND and BCLA'16 did not imply any components. Meanwhile, TNO'88, which only declaratively defines wind actions, does not define any components. Due to this situation, the UC models are not considered in the following discussion of worldwide trends of the models.

Table 4.4 Classification category and regional distribution

No.	Category/ Subcategory		Code/standard	Regional distribution				
				Africa	Americas	Asia	Europe	Oceania
1	WW	AU	AS 1170.2'81, AS 1170.2'89, AS/NZS 1170.2'02, AS/NZS 1170.2'11 (3)	-	-	✓	-	✓
2		BD	BNS CP 28'81, BNS DPC'10, BNS TR 28'13 (1)	-	✓	-	✓	-
3		CA	NBCCA'05, NBCCA'10, NBCCA'15 (1)	-	✓	✓	-	-
4		NL	NEN 6702'07, NEN EN NA'11, OWAW'81, BB1'56 (4)	-	✓	-	✓	-
5		EU	ENV'95, EN'05 (2)	✓	-	✓	✓	-
6		FR	NV 46'47, NV 65'76, NV 65'87, NV 65'00, NV 65'09, NF EN NA'08&'12 (3)	✓	-	✓	✓	-
7		DE	DIN 1055-4'86, DIN EN NA'10 (2)	-	-	✓	✓	-
8		IO	ISO 4354'97 (1)	-	✓	-	✓	-
9		PT	RSEP'61, RSA'83, NP EN NA'10 (3)	✓	-	-	✓	-
10		RU	SNiP 2.01.07'88, SNiP 2.01.07'05, SP 20.13330'11, SP 20.13330'16, SP 201.1325800'14 (2)	-	-	✓	✓	-
11		UK	BS CP3 CV'52, BS CP3 CV2'70, BS CP3 CV2'72, BS 6399.2'97, BS EN NA'10 (4)	✓	✓	✓	✓	✓
12		US	UBC'64, UBC'88, UBC'97, IBC'03, IBC'06, IBC'09, IBC'12, IBC'15, IBC'18, ANSI A58.1'82, ASCE 7'88, ASCE 7'98, ASCE 7'02, ASCE 7'05, ASCE 7'10, ASCE 7'16 (3)	✓	✓	✓	✓	✓
13	RG	BR	NBR 6123'88, NBR 6123'13 (1)	-	✓	-	-	-
14		IN	NBCIN'05, NBCIN'16, IS 875.3'87, IS 875.3'15 (2)	-	-	✓	-	-
15		IT	NTC'18, UNI EN NA'10, CNR-DT 207'08 (1)	-	-	-	✓	-
16		JP	BSL-N 1454'00, AIJ-RLB'93, AIJ-RLB'15 (3)	-	-	✓	-	-
17		MX	RCTB'75, NTCV'87, NTCV'04, NTCV'17 (4)	-	✓	-	-	-
18		PE	RNE'06 (1)	-	✓	-	-	-
19		ZA	SBR'66, SBR '70, SABS 0160'89, SANS 10160-3'10, SANS 10160-3'11, SANS 10160-3'18 (3)	✓	-	-	-	-
20		CH	SIA 261'14, SN EN NA'16 (1)	-	-	-	✓	-
21		YU	TPV'64 (1)	-	-	-	✓	-
22	DS	DS	See Table 4.5 (31)	✓	✓	✓	✓	-
-	UC		BSSKP'ND, BCLA'16, TNO'88 (3)	-	-	✓	✓	-

Note: the numerical value in parentheses: () shows the number of atmospheric boundary layer models.

Table 4.5 List of the DS models and countries developing them

No.	Code/standard	Country	No.	Code/standard	Country	No.	Code/standard	Country
1	SDGUG'05	Uganda	10	GB 50009'12	China	21	ISIRI 519'96	Iran
2	ECP-201'12	Egypt	11	CPWEHK'19		22	BCSY'12	Syria
3	NBCNG'06	Nigeria	12	RSAEEP'96		23	PN EN NA'10	Poland
4	NCP 001-3'73		13	SCBWRD'14		24	DS 410'82	Denmark
5	NC 285'03	Cuba	14	RSAEEP'08		25	SFS EN NA'16	Finland
6	RAVE'80	Dominican Republic	15	MNS 3177'81	Mongolia	26	NS EN NA'09	Norway
			16	KDS 41 10 15'19	South Korea	27	EKS 11'19	Sweden
7	LDVE'23	Costa Rica	17	SNI 03-1727'89	Indonesia	28	KTP 7'78	Albania
8	NCh 432'71	Chile	18	BCAR6'84	Thailand	29	BLR'45	Greece
9	UNIT 50-84'94	Uruguay	19	TCVN 2737'96	Vietnam	30	NBN EN NA'10	Belgium
			20	TCVN 2737'20		31	ONORM EN NA'13	Austria

4.2.2 Classification procedure

The classification of atmospheric boundary layer models into the above categories and subcategories is made through the following two steps.

(1) Individual classification

Three components: wind speed profile, turbulence intensity profile, and turbulence spectrum with turbulence scale profile are individually placed into the category of DS models once and then replaced into any subcategory within the category of WW, RG, or DS models considering the following three criteria:

- if each of the three components is developed in a subcategorized country, it is classified into the subcategory,
- if each of the three components is a carbon copy of the model developed in a subcategorized country (source model), it is classified into the subcategory of the source model, and
- if each of the three components is developed independently or significantly revised from the source model, it is classified into the subcategory of DS models.

In the first criterion, 17 models: AU, BD, BR, CA, NL, FR, DE, IN, IT, JP, MX, PE, PT, RU, ZA, CH, UK, and US are deemed as subcategorized countries. However, the BD model is not considered in this individual classification because it is combined with the UK and US models. In the second criterion, the case where the number of terrain roughness categories is simply reduced from that of the source model is deemed as a carbon copy of the source model. This includes the case where the categories of coastal areas and urban areas are eliminated in inland and small island countries, respectively, from the source model. The EU and IO models, as well as the YU models, are also considered in this criterion. In the third criterion, for example, revisions of roughness heights due to the influence of surrounding buildings are deemed significant in this study.

(2) Overall classification

Subsequently, the subcategory of the set of the three components: atmospheric boundary layer model, is determined based on differences among the subcategories of the three components in accordance with the following two steps:

- if all subcategories of the three components, excluding any undefined ones, are the same, the set is placed into the same subcategory, or
- if any subcategory of the three components, excluding any undefined ones, is different, the set is placed into the subcategory of DS models and then reclassified into any of the remaining 21 subcategories.

4.2.3 Classification results

Table 4.6 organizes the classification results of individual and overall atmospheric boundary layer models adopted in 195 countries. The column, “Code/standard”, shows codes or standards for each country. Hyphens: “-“ in this column denote the five untargeted countries. However, they do not always mean that these countries do not have any codes or standards. The four columns, (a) to (d), show the subcategories of wind speed profile, turbulence intensity profile, turbulence spectrum with turbulence scale profile, and atmospheric boundary layer model, respectively, for each code or standard. Hyphens: “-“ in these columns denote that no information defining all or part of the three components was available for this study. Countries with an asterisk: “*” mean that they require wind-resistant design liability. Codes or standards with “*” mean that they are required for wind-resistant design liability. Although codes or standards without “*” are not necessarily required for wind-resistant design liability, they are widely accepted as de facto industry codes or standards in each country.

Table 4.6 List of the classification of atmospheric boundary layer models in 195 countries

Country	Code/standard	(a)	(b)	(c)	(d)	Country	Code/standard	(a)	(b)	(c)	(d)
Africa						*Cabo Verde	*RSA'83	PT	-	-	PT
Eastern Africa						*NP EN NA'10	PT	PT	PT	PT	
Burundi	NV 65	FR	-	-	FR	*Ivory Coast	NV 65	FR	-	-	FR
Comoros	NV 65	FR	-	-	FR	Gambia	-	-	-	-	-
Djibouti	NV 65	FR	-	-	FR	*Ghana	*BS CP3 CV2'70	UK	-	-	UK
Eritrea	-	-	-	-	-		GS 1207'18	UK	-	-	UK
*Ethiopia	*CES 145'15	EU	EU	EU	EU	Guinea-Bissau	EN'05	EU	EU	EU	EU
Kenya	BS EN NA'10	UK	UK	EU	UK	Guinea-Conakry	NV 65	FR	-	-	FR
*Madagascar	*NV 65'00	FR	-	-	FR	Liberia	ASCE 7	US	US	US	US
*Malawi	MS 820'10	ZA	-	-	ZA	Mali	NV 65	FR	-	-	FR
Mauritius	BS CP3 CV2'72	UK	-	-	UK	*Mauritania	NV 65	FR	-	-	FR
*Mozambique	*RSEP'61	PT	-	-	PT	Niger	NV 65	FR	-	-	FR
	RSA'83	PT	-	-	PT	*Nigeria	*NBCNG'06	DS	-	-	DS
*Rwanda	*RS 144-2'11	EU	EU	-	EU		NCP 001-3'73	DS	-	-	DS
*Seychelles	*BS CP3 CV2'72	UK	-	-	UK	*Senegal	NS 02-058'08	FR	-	-	FR
Somalia	ASCE 7'10	US	US	US	US	Sierra Leone	ASCE 7'10	US	US	US	US
South Sudan	-	-	-	-	-	Togo	NV 65	FR	-	-	FR
*Tanzania	*BS CP3 CV2'72	UK	-	-	UK	Americas					
*Uganda	*SDGUG'05	DS	-	-	DS	Caribbean					
Zambia	BS CP3 CV2'72	UK	-	-	UK	*Antigua and Barbuda	*CUBiC'85	IO	IO	-	IO
*Zimbabwe	*CAS 160.2'77	UK	-	-	UK		BNS DPC'10	UK	US	US	BD
Middle Africa							ASCE 7'05'10	US	US	US	US
Angola	SANS 10160-3'10	ZA	-	-	ZA	*Bahamas	*ASCE 7'88	US	US	US	US
	EN'05	EU	EU	EU	EU	Barbados	BNS TR 28'13	UK	US	US	BD
Cameroon	NV 65'00	FR	-	-	FR	*Cuba	NC 285'03	DS	-	-	DS
Central African Republic	NV 65	FR	-	-	FR	*Dominica	CUBiC'85	IO	IO	-	IO
Chad	NV 65	FR	-	-	FR		BNS DPC'10	UK	US	US	BD
Congo-Brazzaville	NV 65	FR	-	-	FR		ASCE 7'05'10	US	US	US	US
Congo-Kinshasa	NV 65	FR	-	-	FR	Dominican Republic	RAVE'80	DS	-	-	DS
Equatorial Guinea	CTE DB-SE-AE'09	EU	EU	-	EU		RAVE'01	US	-	-	US
Gabon	NV 65	FR	-	-	FR	*Grenada	*CUBiC'85	IO	IO	-	IO
Sao Tome and Principe	NP EN NA'10	PT	PT	PT	PT		*BNS DPC'10	UK	US	US	BD
Northern Africa							*ASCE 7'05'10	US	US	US	US
*Algeria	*DTR RNV'13	EU	EU	EU	EU	Haiti	ASCE 7'05	US	US	US	US
*Egypt	*ECP-201'12	DS	DS	DS	DS	*Jamaica	*ASCE 7'05	US	US	US	US
Libya	ASCE 7	US	US	US	US	*St. Kitts and Nevis	*BNS CP 28'81	UK	US	US	BD
*Morocco	NV 46'47	FR	-	-	FR		CUBiC'85	IO	IO	-	IO
	NV 65'87	FR	-	-	FR		BNS DPC'10	UK	US	US	BD
	PMN EN NA'20	FR	FR	FR	FR		ASCE 7'05'10	US	US	US	US
Sudan	-	-	-	-	-	St. Lucia	CUBiC'85	IO	IO	-	IO
Tunisia	NT 30.185'04	EU	EU	EU	EU		BNS DPC'10	UK	US	US	BD
	NV 65	FR	-	-	FR		ASCE 7'05'10	US	US	US	US
Southern Africa						*St. Vincent and the Grenadines	*CUBiC'85	IO	IO	-	IO
*Botswana	*SBR'70	ZA	-	-	ZA		BNS DPC'10	UK	US	US	BD
	*BS CP3 CV2'72	UK	-	-	UK		ASCE 7'05'10	US	US	US	US
	BOS 536-3'14	ZA	-	-	ZA	Trinidad and Tobago	ASCE 7'05	US	US	US	US
		EU	EU	EU			BNS CP 28'81	UK	US	US	BD
*Eswatini	*SBR'66	ZA	-	-	ZA	Central America					
	SANS 10160-3'18	ZA	-	-	ZA	*Belize	ASCE 7	US	US	US	US
		EU	EU	EU		*Costa Rica	*LDVE'23	DS	US	US	DS
*Lesotho	*SABS 0160	ZA	-	-	ZA	*El Salvador	*NTDV'97	MX	-	-	MX
	*SANS 10160-3	ZA	-	-	ZA	*Guatemala	*AGIES NSE 2'10	US	US	US	US
		EU	EU	EU			ASCE 7'10	US	US	US	US
*Namibia	*SBR'70	ZA	-	-	ZA	Notes:					
	SANS 10160-3'18	ZA	-	-	ZA	(a) Wind speed profile					
		EU	EU	EU		(b) Turbulence intensity profile					
*South Africa	*SANS 10160-3'18	ZA	-	-	ZA	(c) Turbulence spectrum					
		EU	EU	EU		(d) Atmospheric boundary layer model					
Western Africa						* : Country or code/standard for requiring wind-resistant design liability					
Benin	NV 65	FR	-	-	FR						
Burkina Faso	NV 65	FR	-	-	FR						

Table 4.6 List of the classification of atmospheric boundary layer models in 195 countries (cont'd)

Country	Code/standard	(a)	(b)	(c)	(d)	Country	Code/standard	(a)	(b)	(c)	(d)
*Honduras	*CHOC'08	US	US	US	US	*Singapore	*BS 6399.2'97	UK	UK	-	UK
*Mexico	*RCTB'75	MX	-	-	MX		*SS EN NA'09	EU	EU	EU	EU
	*NTCV'17	MX	MX	EU	MX	*Thailand	*BCAR6'84	DS	-	-	DS
*Nicaragua	*RNC'07	MX	-	-	MX		DPT 1311-50'07	CA	CA	CA	CA
*Panama	*ASCE 7'05	US	US	US	US	Timor-Leste	AS 1170.2'89	AU	AU	AU	AU
Northern America							SNI 1727'13	US	US	US	US
*Canada	*NBCCA'10/'15	CA	CA	CA	CA	*Vietnam	*TCVN 2737'96	DS	DS	DS	DS
*United States	*ASCE 7'02'05/'10'16	US	US	US	US		TCVN 2737'20	DS	DS	DS	DS
	*UBC'64	US	-	-	US		EN'05	EU	EU	EU	EU
South America						Southern Asia					
*Argentina	*CIRSOC 102'05	US	US	US	US	Afghanistan	ASC'12	US	US	US	US
*Bolivia	*NB 1225003'14	US	US	US	US		ASCE 7'10	US	US	US	US
	*CIC 103'12	US	US	US	US	*Bangladesh	*NBCBD'15	US	US	US	US
*Brazil	*NBR 6123'13	BR	BR	BR	BR	*Bhutan	*IS 875.3'87	IN	-	IN	IN
*Chile	*NCh 432'71	DS	DS	DS	DS	*India	*NBCIN'05	IN	-	IN	IN
	NCh 432'10	US	US	US	US		*NBCIN'16	IN	IN	IN	IN
*Colombia	*NSR'10	US	US	US	US		*IS 875.3'87	IN	-	IN	IN
*Ecuador	*NEC-SE-CG'14	PE	-	-	PE		*IS 875.3'15	IN	IN	IN	IN
Guyana	BS CP3 CV'52	UK	-	-	UK	*Iran	*NBRIR-6'13	CA	CA	CA	CA
	CUBIC'85	IO	IO	-	IO		ISIRI 519'96	DS	-	-	DS
*Paraguay	*NP 196'91	BR	-	-	BR	*Maldives	BS 6399.2'97	UK	UK	-	UK
*Peru	*RNE'06	PE	-	-	PE		BS CP3 CV2'72	UK	-	-	UK
*Suriname	*BBI'56	NL	-	-	NL	*Nepal	*IS 875.3'87	IN	-	IN	IN
	NEN 6702'07	NL	NL	NL	NL	*Pakistan	*BCP SP'07	US	US	US	US
Uruguay	UNIT 50-84'94	DS	-	-	DS		*BS CP3 CV'52	UK	-	-	UK
*Venezuela	*COVENIN 2003'89	US	US	US	US		*UBC'97	US	US	US	US
Asia							*ASCE 7'02/'05	US	US	US	US
Central Asia						Sri Lanka	BS CP3 CV2'72	UK	-	-	UK
*Kazakhstan	*SN RK EN NA'11	EU	EU	EU	EU		SLS EN NA'16	EU	EU	EU	EU
*Kyrgyzstan	*SNIp 2.01.07'05	RU	RU	RU	RU	Western Asia					
*Tajikistan	*SNIp 2.01.07'05	RU	RU	RU	RU	*Armenia	*SNIp 2.01.07'88	RU	RU	RU	RU
*Turkmenistan	*TGK 2.01.07'05	RU	RU	RU	RU	*Azerbaijan	*AzDTN 2.1-1'15	RU	RU	RU	RU
*Uzbekistan	*KMK 2.01.07'96	RU	RU	RU	RU	Bahrain	BS 6399.2'97	UK	UK	-	UK
Eastern Asia						*Cyprus	*CYS EN NA'10	EU	EU	EU	EU
*China	*GB 50009'12	DS	DS	DS	DS	*Georgia	*SNIp 2.01.07'88	RU	RU	RU	RU
	*CPWEHK'19	DS	DS	-	DS		EN'05	EU	EU	EU	EU
	*RSAEEP'96	DS	-	-	DS	*Iraq	*MBO 301'15	UK	-	-	UK
	*SCBWRD'14	DS	US	US	DS	*Israel	*SI 414'08	EU	EU	EU	EU
	RSAAEP'08	DS	DS	AU	DS	*Jordan	*NBCJO'06	UK	UK	-	UK
*Japan	*BSLN 1454'00	JP	JP	JP	JP	Kuwait	ASCE 7'05	US	US	US	US
	AJJ-RLB'15	JP	JP	JP	JP	*Lebanon	UBC'97	US	US	US	US
*Mongolia	*BNbD 20-04'17	RU	RU	RU	RU		ASCE 7'05	US	US	US	US
	MNS 3177'81	DS	-	-	DS		NV 65'09	FR	-	-	FR
	EN'05	EU	EU	EU	EU		NF EN NA'08	FR	FR	FR	FR
North Korea	BSSKP'ND	-	-	-	-	Oman	BS 6399.2'97	UK	UK	-	UK
*South Korea	*KDS 41 10 15'19	DS	DS	JP	DS	*Palestine	ASCE 7'10	US	US	US	US
South-eastern Asia						*Qatar	*ASCE 7'05/'10	US	US	US	US
*Brunei	*BS CP3 CV2'72	UK	-	-	UK		*BS 6399.2'97	UK	UK	-	UK
	*BS 6399.2'97	UK	UK	-	UK		*BS EN NA'10	UK	UK	EU	UK
	*BS EN NA'10	UK	UK	EU	UK	*Saudi Arabia	*SABC 301'18	US	US	US	US
Cambodia	ASCE 7'05	US	US	US	US	*Syria	*BCSY-1'06	UK	-	-	UK
*Indonesia	*SNI 03-1727'89	DS	-	-	DS		*BCSY'12	DS	-	-	DS
	SNI 1727'13	US	US	US	US	*Turkey	TS 498'97	DE	-	-	DE
Laos	BCLA'16	-	-	-	-	Notes:					
*Malaysia	*MS 1553'02	AU	AU	AU	AU	(a) Wind speed profile					
	*BS CP3 CV2'72	UK	-	-	UK	(b) Turbulence intensity profile					
	*BS 6399.2'97	UK	UK	-	UK	(c) Turbulence spectrum					
	EN'05	EU	EU	EU	EU	(d) Atmospheric boundary layer model					
Myanmar	NBCMM'20	US	US	US	US	* : Country or code/standard for requiring wind-resistant design liability					
*Philippines	*NSCP C101'15	US	US	US	US						
*Singapore	*BS CP3 CV2'72	UK	-	-	UK						

Table 4.6 List of the classification of atmospheric boundary layer models in 195 countries (cont'd)

Country	Code/standard	(a)	(b)	(c)	(d)	Country	Code/standard	(a)	(b)	(c)	(d)
*Turkey	EN'05	EU	EU	EU	EU	*North Macedonia	*MKC EN NA'20	EU	EU	EU	EU
	IYBRY-V'09	EU	EU	EU	EU		*MKC U.C7'91	IO	IO	-	IO
*United Arab Emirates	*ASCE 7'05	US	US	US	US	*Portugal	*RSA'83	PT	-	-	PT
	*DUWC'13	EU	EU	EU	EU		*NP EN NA'10	PT	PT	PT	PT
	*BS 6399.2'97	UK	UK	-	UK	*San Marino	*NTC'18	IT	IT	-	IT
Yemen	-	-	-	-	-	*Serbia	*SRPS EN NA'17	EU	EU	EU	EU
Europe						*Slovenia	*SIST EN NA'08	EU	EU	EU	EU
Eastern Europe						*Spain	*CTE DB-SE-AE'09	EU	EU	-	EU
*Belarus	*CH 2.01.05'19	EU	EU	EU	EU		EN'05	EU	EU	EU	EU
*Bulgaria	*MRDPW'04	RU	RU	RU	RU	Western Europe					
	*BDS EN NA'11	EU	EU	EU	EU	*Austria	ONORM EN NA'13	DS	DS	EU	DS
*Czech	*CSN EN NA'13	EU	EU	EU	EU	Belgium	NBN EN NA'10	EU	DS	EU	DS
*Hungary	*MSZ EN NA'07	EU	EU	EU	EU	*France	*NV 65'76/'87/'00	FR	-	-	FR
*Moldova	*SNiP 2.01.07'88	RU	RU	RU	RU		*NF EN NA'08&'12	FR	FR	FR	FR
	SM EN NA'18	EU	EU	EU	EU		NV 65'09	FR	-	-	FR
*Poland	*PN EN NA'10	DS	EU	EU	DS	*Germany	*DIN EN NA'10	DE	DE	EU	DE
*Romania	*CR 1-1-4'12	EU	EU	EU	EU	*Liechtenstein	SIA 261'14	CH	CH	CH	CH
	SR EN NA'07	EU	EU	EU	EU		SN EN NA'16				
*Russia	*SP 20.13330'16	RU	RU	RU	RU	*Luxembourg	*LU EN NA'11	EU	EU	EU	EU
	SP 201.1325800'14	RU	EU	RU	RU	*Monaco	NV 65	FR	-	-	FR
*Slovakia	*STN EN NA'10	EU	EU	EU	EU		NF EN NA'08	FR	FR	FR	FR
*Ukraine	*DSTU EN NA'10	EU	EU	EU	EU	*Netherlands	*NEN EN NA'11	NL	NL	NL	NL
Northern Europe							OWAW'81	NL	NL	-	NL
*Denmark	*DS EN NA'15	EU	EU	EU	EU		*BESC'15	US	US	US	US
	*DS 410'82	DS	-	DS	DS		*BWB'35	NL	-	-	NL
	GL EN NA'10	EU	EU	EU	EU		UBC'97	US	US	US	US
Estonia	EPN-ENV 1.2.6'96	EU	EU	EU	EU	*Switzerland	*SIA 261'14	CH	CH	CH	CH
	EVS EN NA'07	EU	EU	EU	EU		*SN EN NA'16				
*Finland	*SFS EN NA'10&'16	DS	EU	EU	DS	Oceania					
*Iceland	*IST EN NA'10	EU	EU	EU	EU	Australia and New Zealand					
*Ireland	*IS EN NA'13	UK	UK	EU	UK	*Australia	*AS 1170.2'89	AU	AU	AU	AU
*Latvia	*LVS EN NA'11	EU	EU	EU	EU		*AS/NZS 1170.2'02'11	AU	AU	AU	AU
*Lithuania	*STR 2.05.04'03	RU	RU	RU	RU	*New Zealand	*AS 1170.2'89	AU	AU	AU	AU
	LST EN NA'12	EU	EU	EU	EU		*AS/NZS 1170.2'11	AU	AU	AU	AU
*Norway	*NS EN NA'09	DS	DS	DS	DS		AS/NZS 1170.2'02	AU	AU	AU	AU
*Sweden	*EKS 11'19	EU	EU	DS	DS	Melanesia					
*United Kingdom	*BS CP3 CV2'72	UK	-	-	UK	*Fiji	*AS 1170.2'89	AU	AU	AU	AU
	*BS 6399.2'97	UK	UK	-	UK	*Papua New Guinea	*PNGS 1001.3'82	AU	AU	AU	AU
	*BS EN NA'10	UK	UK	EU	UK	Solomon Islands	AS 1170.2'89	AU	AU	AU	AU
	*CUBiC'85	IO	IO	-	IO	*Vanuatu	*AS 1170.2'89	AU	AU	AU	AU
	*BNS DPC'10	UK	US	US	BD	Micronesia					
	*ASCE 7'05/'10	US	US	US	US	Federated States of Micronesia	ASCE 7'16	US	US	US	US
Southern Europe						*Kiribati	*AS/NZS 1170.2'11	AU	AU	AU	AU
*Albania	*KTP 7'78	DS	-	-	DS	Marshall Islands	ASCE 7'16	US	US	US	US
	EN'05	EU	EU	EU	EU	Nauru	NBCNR'23	AU	AU	AU	AU
Andorra	CSP'89	FR	-	-	FR	Palau	UBC'88	US	US	US	US
	CTE DB-SE-AE'09	EU	EU	-	EU		ASCE 7'05	US	US	US	US
*Bosnia and Herzegovina	*TPV'64	YU	-	-	YU	Polynesia					
	*TNO'88	-	-	-	-	*Samoa	*NZS 4203'84	UK	-	-	UK
	BAS EN NA'18	EU	EU	EU	EU		AS/NZS 1170.2'11	AU	AU	AU	AU
*Croatia	*HRN EN NA'14	EU	EU	EU	EU	*Tonga	*AS/NZS 1170.2'11	AU	AU	AU	AU
*Greece	*BLR'45	DS	-	-	DS	Tuvalu	AS 1170.2'89	AU	AU	AU	AU
	*ELOT EN NA'10	EU	EU	EU	EU	Notes:					
*Holy See	*NTC'18	IT	IT	-	IT	(a) Wind speed profile					
*Italy	*NTC'18	IT	IT	-	IT	(b) Turbulence intensity profile					
	UNI EN NA'13	IT	IT	IT	IT	(c) Turbulence spectrum					
	CNR DT 207'08	IT	IT	IT	IT	(d) Atmospheric boundary layer model					
Malta	EN'05	EU	EU	EU	EU	* : Country or code/standard for requiring wind-resistant design liability					
*Montenegro	*TPV'64	YU	-	-	YU						
	*TNO'88	-	-	-	-						
	*MEST EN NA'16	EU	EU	EU	EU						

4.3 Worldwide Trends

The current worldwide trends of atmospheric boundary layer models are discussed based on the following three groups of countries:

- requiring models in 22 subcategories within the legal and regulatory frameworks,
- accepting models in 22 subcategories in countries with a legal and regulatory framework, and
- accepting models in 22 subcategories in countries with or without a legal and regulatory framework.

The first group consists of models of codes or standards with an asterisk in Table 4.6, which have already been incorporated within the legal and regulatory frameworks. The second group consists of models for countries with an asterisk in Table 4.6, which have been consulted in practice in countries with legal and regulatory frameworks. Some of them have a high possibility of superseding current models within the legal and regulatory frameworks in the future. The third group consists of all models in Table 4.6, which have been consulted in practice. Some of them may not necessarily be incorporated within the legal and regulatory frameworks even in the future. However, they are consulted in practice in accordance with administrative guidance from or technical consultations with authorities. Therefore, the current overall picture of codes and standards worldwide should be understood through this third group. Figure 4.3 shows the inclusive relationship among these groups. The horizontal axis represents the number of countries belonging to the first, second and third groups, which are 137, 137, and 190 countries, respectively. On the other hand, the vertical axis represents the total number of subcategories accumulated by respective groups after all models adopted in 190 countries were classified into 22 subcategories, as per Table 4.6. However, because subcategory duplications are excluded in each country, it represents the total number of countries, which are 139, 178, and 241 for the first, second, and third groups, respectively.

Figure 4.4 and Figure 4.5 show the breakdown of countries adopting the WW models and the RG or DS models, respectively, for each subcategory. Here, bars at the top, middle, and bottom show the number of countries that belong to the first, second, and third group, respectively. Bars colored red, blue, yellow, green, and orange represent the number of countries in Africa, the Americas, Asia, Europe, and Oceania, respectively. The numerical value in parentheses: () shows the percentage of the 195 countries. Figure 4.6 to Figure 4.10 show the distribution of respective models on the world map. These figures individually show the status of 30 small countries with less than 5,000 km².

These figures show that the EU and US models are defined in 26 and 18 countries for the first group, whose proportions to the 195 countries are 13.3% and 9.2%, respectively, and accepted in 35 and 27 countries for the second group, whose proportions to the total are 17.9% and 13.8%, respectively. For the third group, both are also accepted in 43 countries, whose proportion to the total is 22.1%. These facts confirm that the EU and US models are the most accepted in the world. They are followed by the UK, FR, AU, and RU models, whose numbers of countries and proportions to the total are 25, 25, 13, and 12 countries and 12.8%, 12.8%, 6.7%, and 6.2%, respectively. Regionally, the EU, US, FR, and AU models are predominantly accepted in Europe, the Americas, Africa, and Oceania, respectively. The EU, RU, UK, US, and DS models are also widely accepted in Asia. Of these, the FR and UK models have a distinctive trend. The FR models are accepted in only two and eight countries for the first and second groups, which

are just 1.0% and 4.1% of the total, respectively. However, the FR models are accepted in 25 countries for the third group, accounting for 12.8% of the total. As such, the FR models are accepted in countries without the legal and regulatory framework, many of which are concentrated in Africa. Besides, it is worth noting that the UK models are more widely accepted in Africa and Asia than in Europe. On the other hand, the CA, NL, DE, PT, RU, BR, IN, IT, JP, MX, PE, CH, and YU models for the third group have almost the same number of acceptances as those for the first and second groups. The DS models are accepted in 18, 22, and 26 countries for the first, second, and third groups, whose proportions to the total are 9.2%, 11.3%, and 13.3%, respectively. Many of them are developed in Asia and Europe.

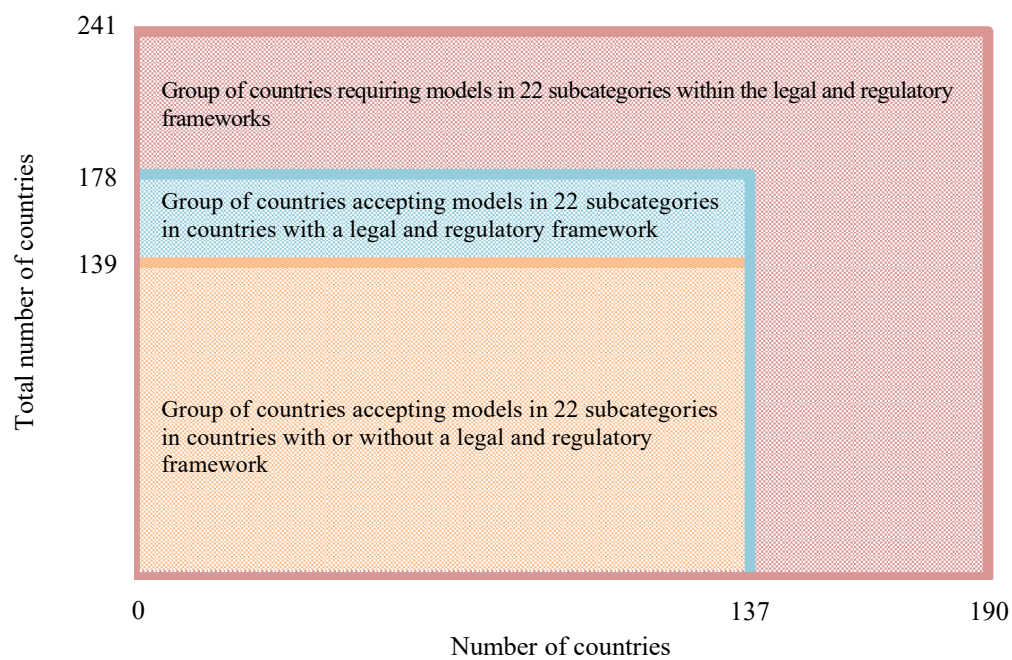


Figure 4.3 Inclusive relationship among three groups of countries

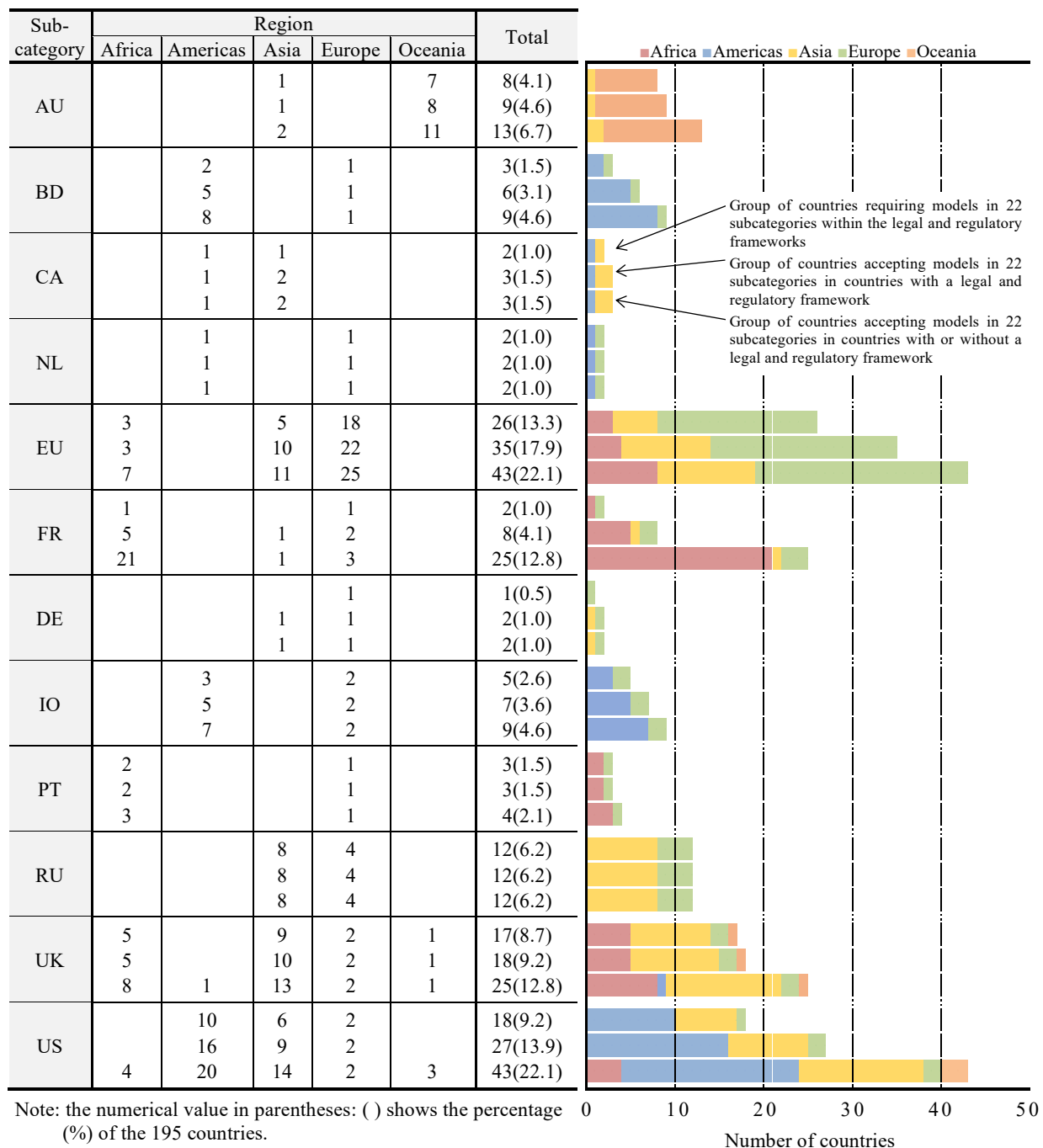


Figure 4.4 Breakdown of countries adopting the WW models for each subcategory

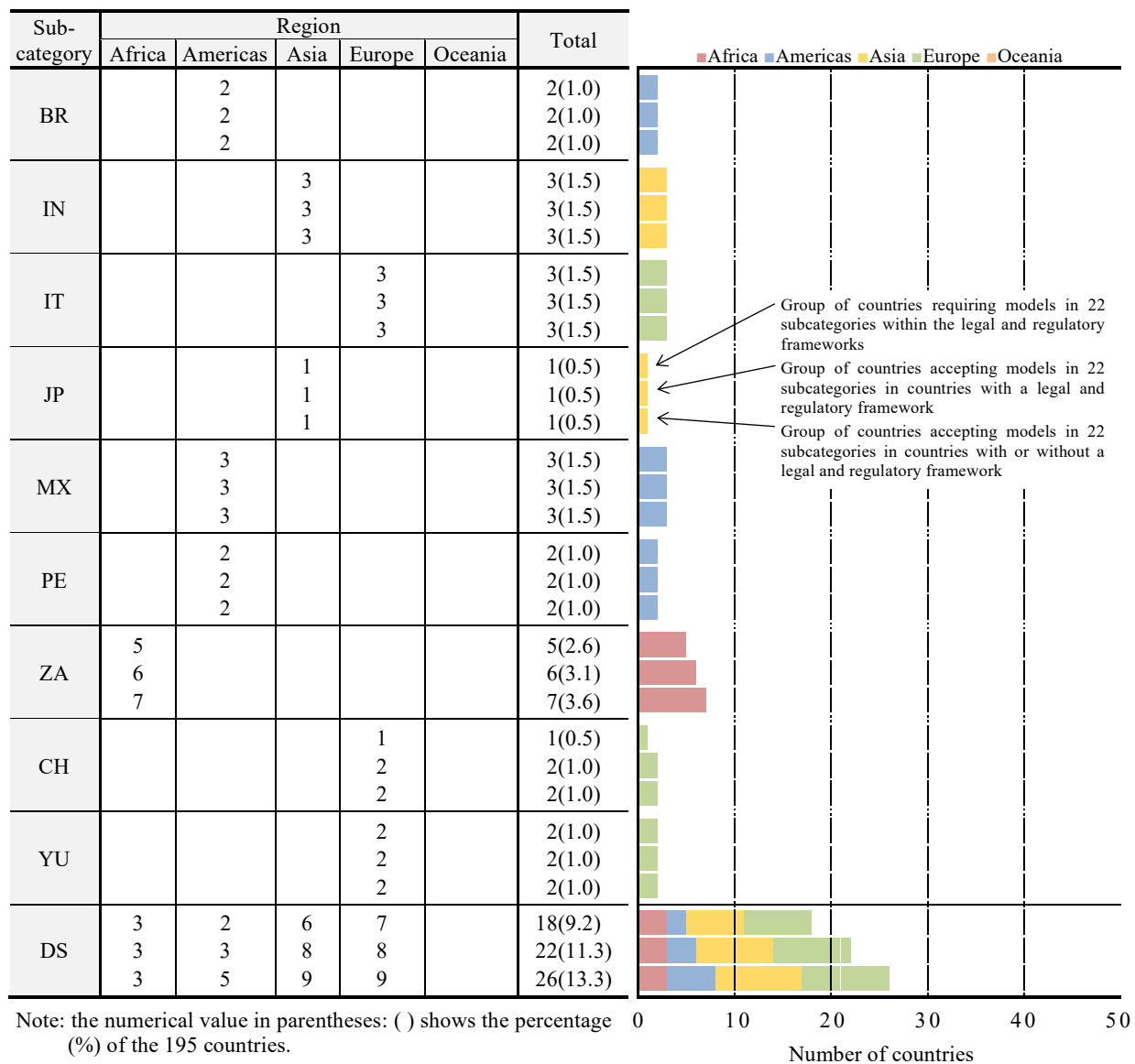


Figure 4.5 Breakdown of countries adopting the RG or DS models for each subcategory

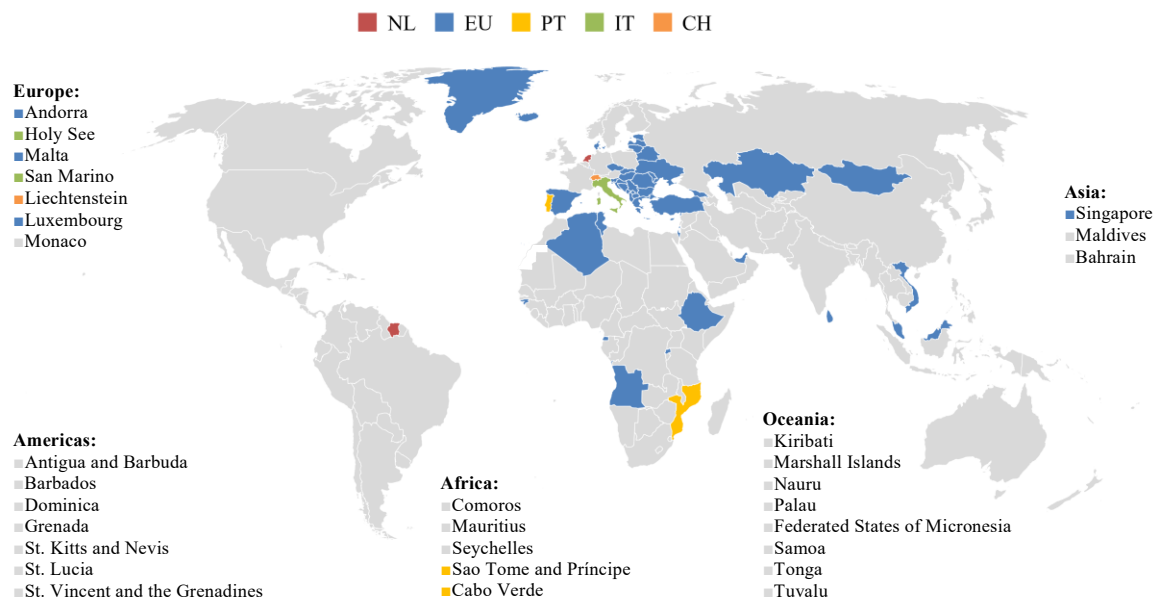


Figure 4.6 Distribution of countries adopting the NL, EU, PT, IT, or CH models

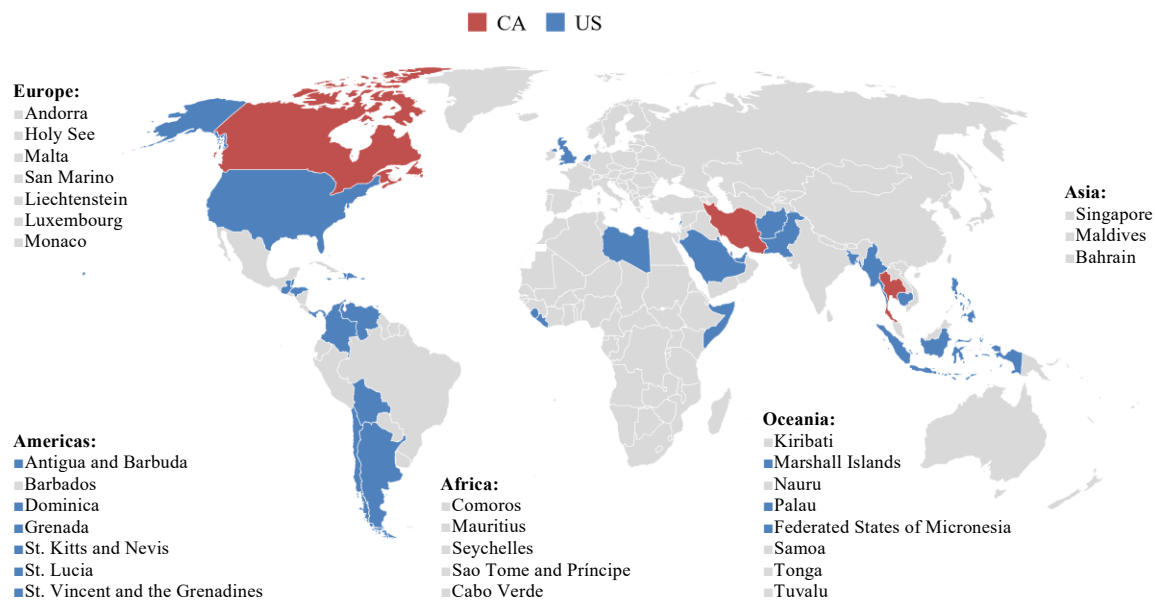


Figure 4.7 Distribution of countries adopting the CA or US models

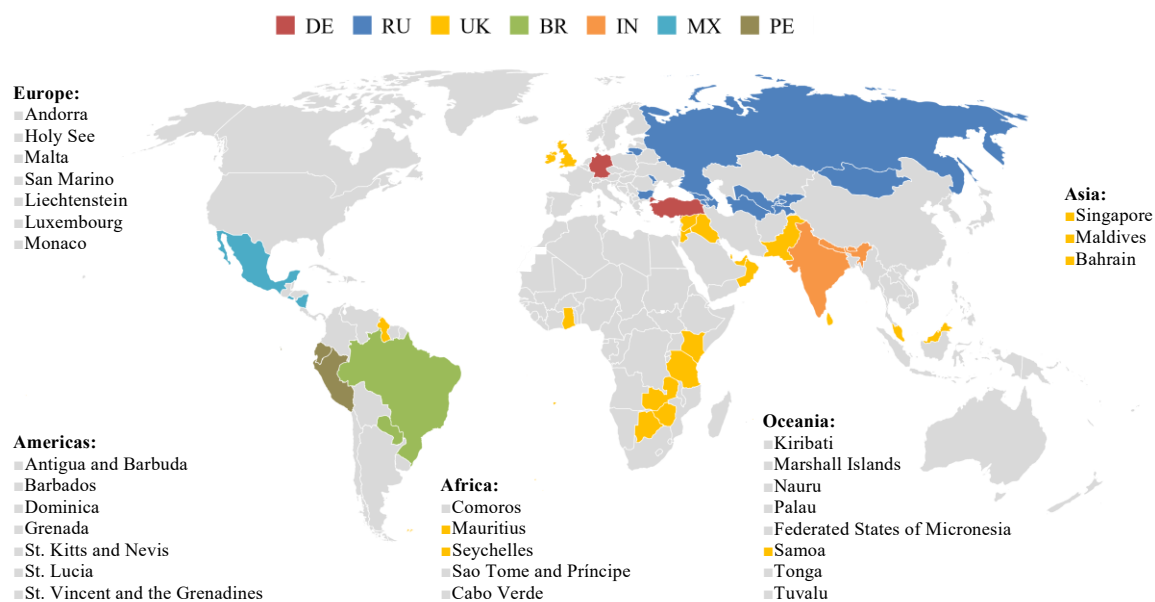


Figure 4.8 Distribution of countries adopting the DE, RU, UK, BR, IN, MX, or PE models

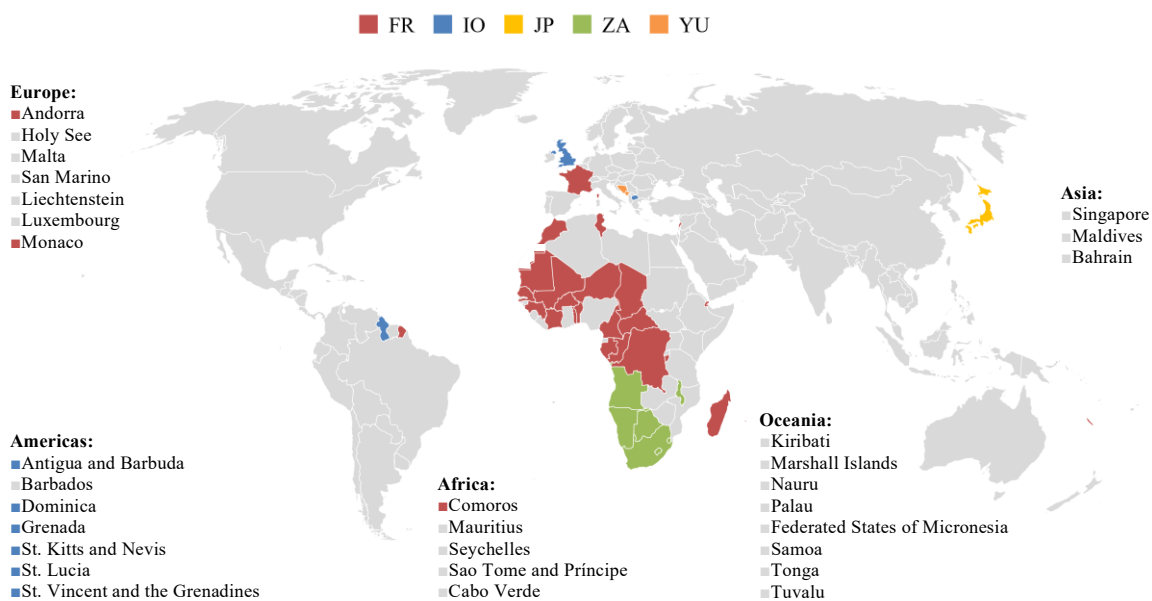


Figure 4.9 Distribution of countries adopting the FR, IO, JP, ZA, or YU models

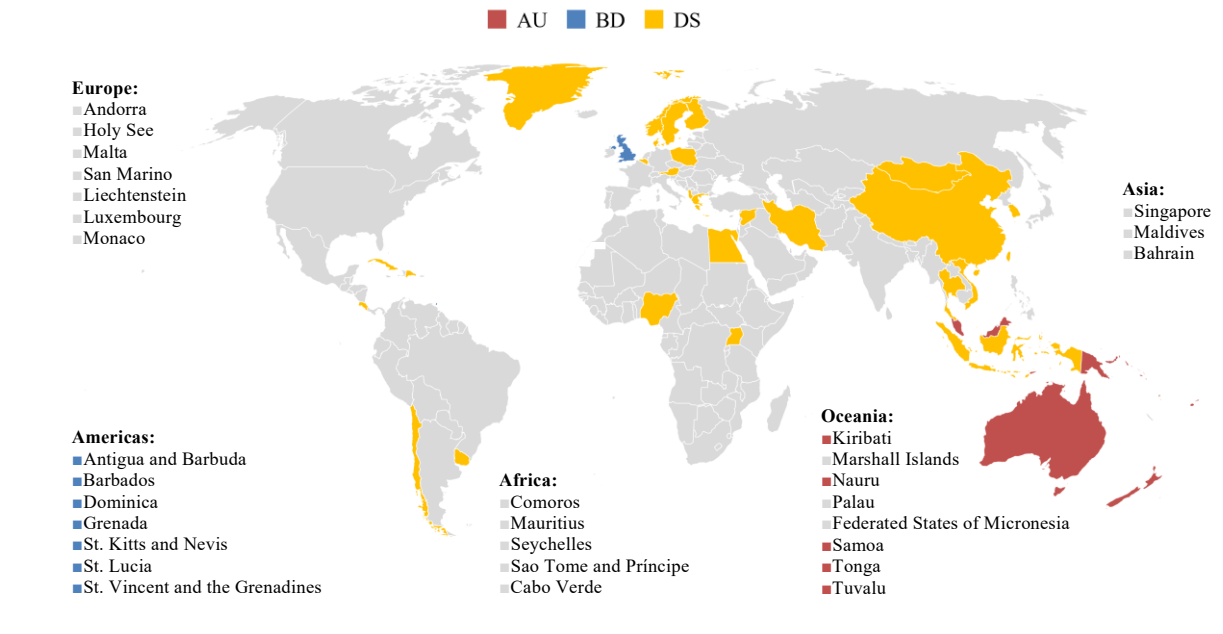


Figure 4.10 Distribution of countries adopting the AU, BD, or DS models

4.4 Regional or National Initiatives

Regional or national initiatives should indicate the potential future development of codes and standards. We discuss the future trends of the top two models: EU and US, through regional or national initiatives in regions or countries in transition phases.

Table 4.7 shows countries likely to mainstream the EU or US models in the future. For two EU member countries: Bulgaria and Greece, the EU models are supposed to supersede the old existing models. For 13 non-EU member countries: Angola, Tunisia, Mongolia, Malaysia, Singapore, Vietnam, Sri Lanka, Georgia, Turkey, Moldova, Albania, Bosnia and Herzegovina, and Montenegro, and one non-EU member overseas territory, Denmark (Greenland), some ongoing efforts have been made to mainstream the EU models. Therefore, the YU model will fall out of the mainstream. On the other hand, for 14 American countries: Antigua and Barbuda, Bahamas, Barbados, Dominica, Grenada, Haiti, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago, Belize, Guyana, and Suriname, as well as for one overseas territory of a European country: the United Kingdom (Montserrat), the regional action principle that follows the US models has been formulated by the regional standard setting body. (CROSQ 2010) Therefore, the BD and IO models will fall out of the mainstream. Also, for seven Asian countries: Bahrain, Kuwait, Qatar, Oman, Saudi Arabia, the United Arab Emirates, and Yemen, the multilateral agreement on the development of structural codes, which follow the US models, has been concluded by the regional standard setting body. (SASO 2016) Moreover, some ongoing efforts to mainstream the US models or to develop new codes or standards based on the US models have been made in three countries: Dominican Republic, Chile, and Indonesia. Pakistan is likely to mainstream the US models instead of the UK models across the country, given that the current ministerial code follows the US models. These facts suggest that the EU and US models are likely to supersede some other existing models and become more polarized in terms of the number of countries. However, the number of DS models is likely to increase due to economic development or knowledge accumulation in developing countries.

Incidentally, two countries: Botswana and Samoa are supposed to mainstream the ZA and AU models, respectively, instead of the UK models. Therefore, at least seven countries: Botswana, Guyana, Pakistan, Bahrain, Oman, Qatar, and Samoa have the possibility of withdrawing from the UK models. Meanwhile, almost the same number of countries, mainly in Africa, will continue to adopt the FR models or the ZA models for the time being. The same trend will apply to the AU models in Oceania, as well as the CA, NL, DE, PT, BR, IN, IT, JP, MX, PE, ZA, and CH models. Of these, the PE model is so simple that it is likely to be replaced by other models in the future. Although seven countries: Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan, Armenia, Azerbaijan, and Russia are expected to transition to the EU models from the RU models, their current or future trends are uncertain.

Figure 4.11 shows countries likely to adopt the AU, EU, FR, RU, UK, US, or other models on the world map. This figure individually shows the status of 30 small countries with less than 5,000 km². This figure demonstrates that the EU and US models are not always dominant worldwide, in regard to the area of countries, because four countries with large areas: Canada, Brazil, China, and India are expected to continue adopting the DS models. Furthermore, future trends in Russia or its neighboring countries definitely have a major impact on the spread of the EU models.

Table 4.7 Countries likely to mainstream the EU or US models

Category	Country
EU	<p>16 countries:</p> <ul style="list-style-type: none"> - 2 African countries: Angola, Tunisia - 7 Asian countries: Mongolia, Malaysia, Singapore, Vietnam, Sri Lanka, Georgia and Turkey - 7 European countries: Bulgaria, Denmark (Greenland), Moldova, Albania, Bosnia and Herzegovina, Greece, Montenegro
US	<p>26 countries:</p> <ul style="list-style-type: none"> - 16 American countries: Antigua and Barbuda, Bahamas, Barbados, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago, Belize, Chile, Guyana, Suriname - 9 Asian countries: Indonesia, Pakistan, Bahrain, Kuwait, Qatar, Oman, Saudi Arabia, United Arab Emirates, Yemen - 1 European country: the United Kingdom (Montserrat)

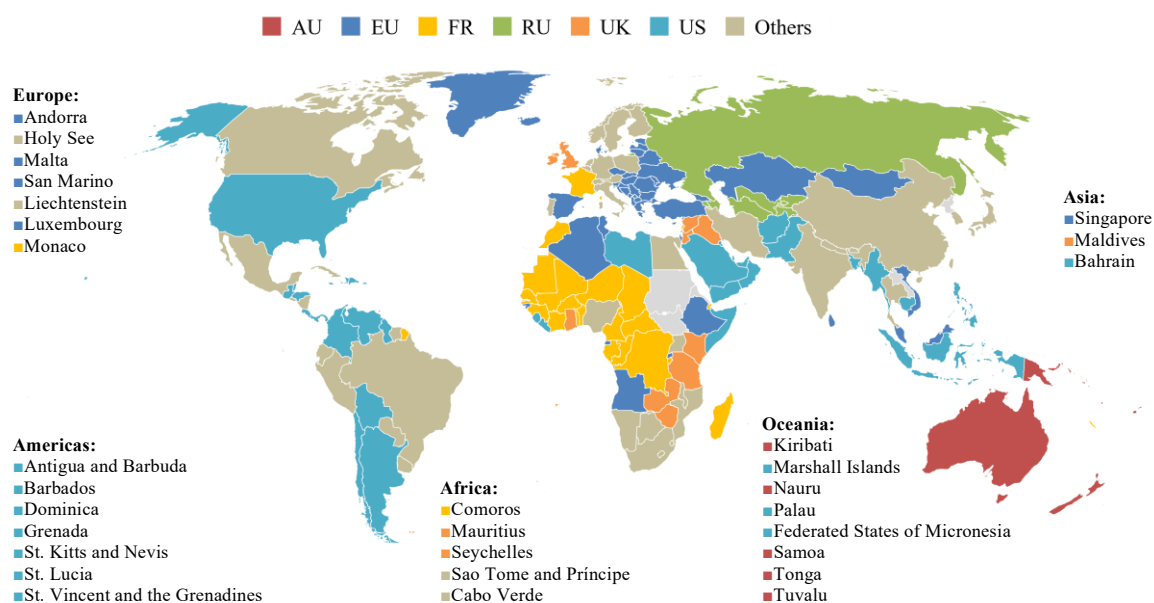


Figure 4.11 Distribution of countries likely to adopt the AU, EU, FR, RU, UK, US, or other models

4.5 Conclusions

This chapter discussed worldwide trends of 176 codes and standards in 190 countries to compile an overall picture of codes and standards worldwide from the perspective of atmospheric boundary layer models. First, we reviewed atmospheric boundary layer models as engineering models for categorizing codes and standards. Next, we defined classification categories and classified the models into three categories and 22 subcategories. Then, we studied the current worldwide trends of these 176 codes and standards. Finally, we discussed the future trends of primarily the EU and US models from regional or national initiatives in regions or countries in transition phases. The study results are summarized as follows:

(1) Category classification

- Atmospheric boundary layer models are classified into three categories: WW, RG, and DS, based on their extent of spread to other regions or countries, as well as 22 subcategories including: AU, BD, BR, CA, NL, EU, FR, DE, IN, IO, IT, JP, MX, PE, PT, RU, ZA, CH, UK, US, YU, and DS, based on their country or international organization of origin.
- Twelve models: AU, BD, CA, NL, EU, FR, DE, IO, PT, RU, UK, and US, which are accepted in multiple regions of Africa, the Americas, Asia, Europe, and Oceania, are classified into the category of WW models. Nine models: BR, IN, IT, JP, MX, PE, ZA, CH, and YU, which are accepted only in any region of Africa, the Americas, Asia, Europe, or Oceania, are classified into the category of RG models.
- Of the WW models, two models: UK and US are accepted in all five regions, and two models: EU and FR are accepted in three regions: Africa, Asia, and Europe. The remaining eight models: AU, BD, CA, NL, DE, IO, PT, and RU are accepted in two regions including their own region.
- Three models: IO, PE, and YU, which consist of a single set of models, do not define any of the three components: wind speed profile, turbulence intensity profile, or turbulence spectrum. 10 models: NL, FR, DE, PT, UK, US, IN, MX, ZA, and DS, which consist of multiple sets of models, have at least one model that does not define any of the three components.
- The DS models consist of 31 models in 25 countries, including three countries with multiple models: Nigeria with two models, China with five models, and Vietnam with two models. The parallel use with the WW and RG models is also accepted in 11 countries: Dominican Republic, Chile, Mongolia, Indonesia, Thailand, Vietnam, Iran, Syria, Denmark (Greenland), Albania, and Greece. There are no DS models in Oceania.

(2) Worldwide trends

- Two models: EU and US are the most widely accepted worldwide, being adopted in 43 countries, accounting for 22.1% of the total. They are followed by four models: UK, FR, AU, and RU, whose numbers of countries and proportions to the total are 25, 25, 13, and 12, and 12.8%, 12.8%, 6.7%, and 6.2%, respectively.

- Four models: EU, US, FR, and AU have a definite influence particularly on four regions: Europe, the Americas, Africa, and Oceania, respectively. Five models: EU, RU, UK, US, and DS are also widely accepted in Asia.
- The FR models are commonly accepted in African countries without wind-resistant design liability. The UK models are more widely accepted in Asia than in Europe. The DS models are mostly developed in Asian and European countries.
- Thirteen models: CA, NL, DE, PT, RU, BR, IN, IT, JP, MX, PE, CH, and YU are almost the same number of countries with or without wind-resistant design liability.

(3) Regional or national initiatives

- Two models: EU and US are expected to become more polarized in terms of the number of countries. Meanwhile, it is hard to imagine that any other models will be more acceptable than ever before.
- The EU and US models are not always dominant worldwide regarding the area of countries. Future trends in Russia or its neighboring countries, which are expected to transition to the EU models, definitely have a major impact on the spread of the EU models.

This chapter contributed to a specific objective of this thesis: revealing worldwide trends of codes and standards for wind-resistant design of buildings and discussing future trends.

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5 WIND SPEED CONVERSIONS TO VARIOUS AVERAGING TIMES

In this chapter, we explore a unified approach for practically comparing reference wind speeds in national border areas, while ensuring respect for atmospheric boundary layer models defined in laws, regulations, codes, and standards of each country to enhance the effectiveness of this initiative. This approach involves the theory of deriving the statistical distribution of the maxima of a stationary random function. First, we review the theory applied to averaging time conversions of wind speeds. Next, we examine specific atmospheric boundary layer models defined in 176 codes and standards. Then, we compute peak factors for obtaining wind speeds with various averaging times based on the reviewed theory. Finally, we discuss some practical considerations in comparisons of reference wind speeds in national border areas by demonstrating wind speed conversion factors as a practical application example.

As mentioned in Chapter 1, this initiative was triggered by the issue of reference wind speeds, which had been repeatedly discussed at APEC-WW.

Relevant journal paper:

- Hayakawa, A. 2023. “Conversion of Wind Speeds to Various Averaging Times Based on 176 Codes and Standards for Wind-resistant Design of Buildings”, *Journal of Wind Engineering, JAWE*, 48(3(176)),1(1)-13(13).

5.1 Derivation of Wind Speed Conversion Factors

The expected maximum time-averaged wind speed $\hat{U}(z, \tau, T)$ (m/s) at height z (m) above ground in the u -direction for averaging time τ (s) occurring in sampling length T (s) is given by

$$\hat{U}(z, \tau, T) = \bar{U}(z) + \hat{u}(z, \tau, T), \quad (5.1)$$

as illustrated in Figure 5.1, where $\bar{U}(z)$ (m/s) and $\hat{u}(z, \tau, T)$ (m/s) are the expected T -averaged wind speed and the expected maximum τ -averaged fluctuating wind speed, respectively. Here, $\hat{U}(z, \tau, T)$ (ESDU 2002) is given by

$$\frac{\hat{u}(z, \tau, T)}{\bar{U}(z)} = \frac{\hat{u}(z, \tau, T)}{\sigma_u(z, \tau, T)} \cdot \frac{\sigma_u(z, \tau, T)}{\sigma_u(z)} \cdot \frac{\sigma_u(z)}{\bar{U}(z)} = g_u(z, \tau, T) \frac{\sigma_u(z)}{\bar{U}(z)}, \quad (5.2)$$

where $g_u(z, \tau, T)$ is peak factor and $\sigma_u(z)/\bar{U}(z)$ is turbulence intensity $I_u(z)$. Also, a standard deviation of fluctuating wind speeds $\sigma_u(z)$ (m/s) is given by the integral of turbulence spectrum $S_u(z, n)$ (m^2/s), which is a function of frequency n (Hz):

$$\sigma_u^2(z) = \int_0^\infty S_u(z, n) dn. \quad (5.3)$$

Hence, wind speed conversion factor $G_u(z, \tau, T)$ is given by

$$G_u(z, \tau, T) = 1 + g_u(z, \tau, T) I_u(z). \quad (5.4)$$

Given that τ -averaged fluctuating wind speed $u(z, \tau, T)$ (m/s) is a stationary random variable with a normal probability distribution, $\hat{u}(z, \tau, T)/\sigma_u(z, \tau, T)$ (Hino 1964) is derived from the probability distribution for the maxima of $u(z, \tau, T)$ as below:

$$\frac{\hat{u}(z, \tau, T)}{\sigma_u(z, \tau, T)} = \int_0^\infty 1 - \left[1 - \frac{\mu_0(z, \tau, T)}{\mu_l(z, \tau, T)} e^{-\frac{u^2(z, \tau, T)}{2}} \right]^{T\mu_l(z, \tau, T)} du \quad (5.5)$$

or its asymptotic approximation:

$$\frac{\hat{u}(z, \tau, T)}{\sigma_u(z, \tau, T)} = \sqrt{2 \ln[T\mu_0(z, \tau, T)]} + \frac{0.577}{\sqrt{2 \ln[T\mu_0(z, \tau, T)]}}, \quad (5.6)$$

where $\mu_0(z, \tau, T)$ and $\mu_l(z, \tau, T)$ are the expected number of zero per second and the expected number of maxima per second, respectively, and are given by

$$\mu_0(z, \tau, T) = \frac{1}{2\pi} \frac{\rho_u(z, \tau, T)}{\sigma_u(z, \tau, T)} \quad \text{and} \quad (5.7)$$

$$\mu_l(z, \tau, T) = \frac{1}{2\pi} \frac{\nu_u(z, \tau, T)}{\rho_u(z, \tau, T)}. \quad (5.8)$$

An empirical model of $S_u(z, n)$ is usable for a more satisfactory approach to $\hat{u}(z, \tau, T)$. However, the effect of finite τ and T on $S_u(z, n)$ is to effectively confine $S_u(z, n)$ to a spectral window truncated at some low frequency depending on T and at some high frequency dependent on τ . Therefore, $\sigma_u(z, \tau, T)$,

$\rho_u(z, \tau, T)$, and $v_u(z, \tau, T)$ are given by

$$\sigma_u^2(z, \tau, T) = \int_0^\infty S_u(z, n, \tau, T) dn, \quad (5.9)$$

$$\rho_u^2(z, \tau, T) = (2\pi)^2 \int_0^\infty n^2 S_u(z, n, \tau, T) dn, \text{ and} \quad (5.10)$$

$$v_u^2(z, \tau, T) = (2\pi)^4 \int_0^\infty n^4 S_u(z, n, \tau, T) dn, \quad (5.11)$$

where the filtered spectrum $S_u(z, n, \tau, T)$ (ESDU 2002) is expressed as

$$S_u(z, n, \tau, T) = S_u(z, n) \Phi(n, \tau, T) = S_u(z, n) \left[\frac{\sin^2(\pi \tau n)}{(\pi \tau n)^2} - \frac{\sin^2(\pi T n)}{(\pi T n)^2} \right], \quad (5.12)$$

using a τ -moving average filter $\Phi(n, \tau, T)$. $\sigma_u(z, \tau, T)$ is the zeroth order raw moment, which shows the area of $S_u(z, n, \tau, T)$, and $\rho_u(z, \tau, T)$ and $v_u(z, \tau, T)$ are the second and fourth order central moments, respectively, which show the variance and kurtosis of $S_u(z, n, \tau, T)$.

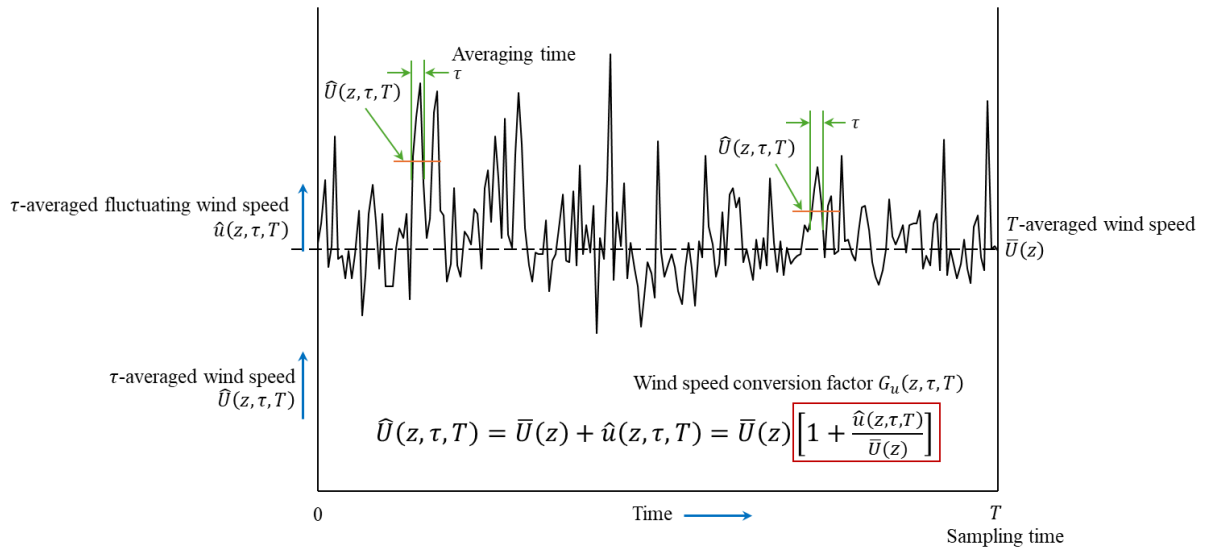


Figure 5.1 Wind speed conversion factor

5.2 Atmospheric Boundary Layer Models

Based on the above theory, $\hat{U}(z, \tau, T)$ (m/s) is expressed by $\bar{U}(z)$, $I_u(z)$, and $S_u(z, n)$, which describe atmospheric boundary layers. Of these, $\bar{U}(z)$ is expressed as the product of reference wind speed U_{ref} (m/s) and wind speed profile $K_u(z)$, and $S_u(z, n)$ includes turbulence scale profile $L_u(z)$ as an important parameter. This section examines U_{ref} , $K_u(z)$, $I_u(z)$, $S_u(z, n)$, and $L_u(z)$ (m) of 176 codes and standards, which were identified as five of six components of atmospheric boundary layer models reviewed in Chapter 4.

It should be noted that this section also assumes comparisons through design wind speeds in national border areas, considering the specifications of reference wind speeds likely to differ from country to country.

5.2.1 Reference wind speed

Reference wind speed U_{ref} is defined as the wind speed in the u-direction averaged over any period, referenced to any height over any terrain roughness, for any probability of exceedance in one year. Instead of U_{ref} , however, some codes and standards such as NBCCA'15, GB 50009'12, and SP 20.13330'16 define reference velocity pressure q_{ref} (N/m²). Table 5.1 organizes specifications of U_{ref} or q_{ref} defined in 164 of 176 codes and standards. Table 5.2 summarizes special notes on U_{ref} or q_{ref} considered in organizing Table 5.1. Table 5.1 confirms that many codes and standards prepare U_{ref} or q_{ref} . Their specifications are summarized in Table 5.3 and as below.

(1) Averaging time

164 codes and standards define U_{ref} or q_{ref} as any of 3-second average wind speed, 20-second average wind speed, 1-minute average wind speed (including fastest-mile wind speed), 10-minute average wind speed, 1-hour average wind speed, or wind speed with no defined averaging time. Each typical code or standard includes ASCE 7'16, BCSY-1'06, ANSI A58.1'82, EN'05, NBCCA'15, and KTP 7'78. Of these, BCSY-1'06 and its superordinate code: BCSY'12 defines a conversion factor from 20-second average wind speed into 3-second average wind speed. CPWEHK'19 and TPV'64 refer to the previous edition: CPWEHK'04 (BD 2004) and the reference book (Bojovic 1993), respectively. Some codes and standards such as NV 65'09 define U_{ref} or q_{ref} as instantaneous wind speed. It is denoted as τ in Table 5.1.

(2) Height and level

Most codes and standards define U_{ref} or q_{ref} at 10 m above ground level (AGL). Some codes and standards such as BS 6399.2'97, BS EN NA'10, PN EN NA'10, and UNI EN NA'12 define U_{ref} at 10 m above sea level (ASL). CPWEHK'19 and RSAEEP'08 define U_{ref} or q_{ref} at 500 m and 250 m AGL, respectively. BS CP3 CV'52 defines U_{ref} at 12.2 m ASL. NCh 432'71 defines U_{ref} at different heights AGL for each terrain roughness. Meanwhile, some codes and standards that do not specify any reference heights such as BB1'56 and TS 498'97 show U_{ref} or q_{ref} at a height which begins to vary from a constant value as the height AGL rises. BK'17 accepts statistically analyzed wind speeds as U_{ref} , whose heights

AGL or terrain roughness is not perfectly aligned. The height AGL or ASL is denoted as z in Table 5.1.

(3) Terrain roughness

Most codes and standards define U_{ref} or q_{ref} for winds from level ground with few obstructions like the countryside, which roughly corresponds to Category 2 defined in ISO 4354'09 (see Table 4.2). However, some codes and standards such as BS CP3 CV2'72 and RSAEEP'08 define U_{ref} or q_{ref} for winds from the sea, which roughly corresponds to Category 1 defined in ISO 4354'09. NTDV'97 define U_{ref} or q_{ref} for winds from medium and low-rise buildings or wooded areas, which roughly corresponds to Category 3 defined in ISO 4354'09. However, not a few codes and standards define U_{ref} or q_{ref} without specifying any terrain roughness. "Category" and "ISO" in Table 5.1 indicate reference terrain roughness category in each code and standard and its corresponding category in ISO 4354'09, respectively. Here, "reference terrain roughness" means a terrain roughness which defines reference wind speeds.

(4) Return period

Many codes and standards define U_{ref} or q_{ref} with a 50-year return period. Some codes and standards define U_{ref} or q_{ref} with other return periods such as 5 years, 20 years, and 100 years. Each typical code or standard includes SNiP 2.01.07'05, TCVN 2737'96, and KDS 41 10 15'19. On the other hand, some internationally recognized codes or standards such as NBCCA'15, ASCE 7'16, AIJ-RLB'15, and AS/NZS 1170.2'11 define U_{ref} or q_{ref} with multiple return periods. In such cases, a representative return period is listed. TPV'64 refers to the reference book (Bojovic, 1993). It is denoted as R_{ref} in Table 5.1.

(5) Air density

Most codes and standards define air density ρ (kg/m³), which links q_{ref} with U_{ref} , as ranging from 1.18 to 1.29. However, FLK'95 and GL EN NA'10 define ρ as 1.85 and 2.00, respectively. BCP SP'07 and UBC'88 list ρ corresponding to the range of reference wind speeds in the countries that adopt them.

Table 5.1 Specifications of reference wind speeds defined in 164 codes and standards

Code/standard	Country	U_{ref} (m/s)	q_{ref} (kN/m ²)	ρ (kg/m ³)	τ (s)	z (m) and level	Roughness		R_{ref} (yrs)
							Category	ISO	
AGIES NSE 2'10	Guatemala	28-33	-	1.23	fastest-mile	10 AGL	C	2	50
AIJ-RLB'15	Japan	30-50	-	1.22	600	10 AGL	II	2	100
AS 1170.2'89	Australia (Norfolk Island)	60	-	1.2	3	10 AGL	2	2	1000
	New Zealand (Tokelau, Niue)	60	-						
	Fiji	70	-						
	Vanuatu	70	-						
	Tuvalu	60	-						
	Timor-Leste	38	-						20
AS/NZS 1170.2'02/'11	Australia	45-88	-	1.2	3	10 AGL	2	2	500
	New Zealand	45-51	-						
	Solomon Islands	69	-						
	Nauru	40	-						
	Samoa	70	-						
	Tonga	70	-						
	New Zealand (Cook Islands)	60	-						-
	Kiribati	40	-						
ASC'12	Afghanistan	20-50	-	1.23	3	10 AGL	C	2	-
ASCE 7'88	Bahamas	49	-	1.23	fastest-mile	10 AGL	C	2	50
ASCE 7'02/'05	Antigua and Barbuda	56	-	1.23	3	10 AGL	C	2	50
	Dominica	56	-						
	Grenada	55	-						
	Haiti	45-58	-						
	St. Kitts and Nevis	58	-						
	St. Lucia	55	-						
	St. Vincent and the Grenadines	55	-						
	Trinidad and Tobago	52-58	-						
	United States	38-76	-						
	Panama	32-39	-						
	Lebanon	45	-						
	Qatar	38	-						
	United Arab Emirates (Abu Dhabi)	40	-						
	United Arab Emirates (Dubai, Ras Al Khaimah)	45	-						
ASCE 7'10	United Kingdom (Anguilla, Montserrat, Turks and Caicos Islands, Virgin Islands)	55-60	-						
	Kuwait	17-43	-		600		-	-	100
	Qatar	38	-		3	10 AGL	C	2	50
	Antigua and Barbuda	72	-						700
	Dominica	71	-						
	Grenada	69	-						
	Jamaica	63-67	-						
	St. Kitts and Nevis	73	-						
	St. Lucia	69	-						
	St. Vincent and the Grenadines	69	-						
	United States	49-87	-						
	United Kingdom (Anguilla, Montserrat, Virgin Islands)	72-76	-						
	United States	40-87	-	1.23	3	10 AGL	C	2	700
	Marshall Islands	58	-	1.23	3	10 AGL	C	2	700
AzDTN 2.1-1'15	Azerbaijan	-	0.17-0.85	1.22	600	10 AGL	A	1/2	50
BAS EN NA'18	Bosnia and Herzegovina	20-35	-	1.25	600	10 AGL	II	2	50
BB1'56	Suriname	-	0.59	-	-	20 AGL	-	-	-
BCP SP'07	Pakistan	33-36	-	1.21	fastest-mile	10 AGL	C	2	50
BCSY-1'06	Syria	35-58	-	1.23	20	10 AGL	1	1	50
BCSY'12	Syria	35-58	-	1.23	20	10 AGL	plains	2	50
BDS EN NA'11	Bulgaria	-	0.18-0.8	1.25	600	10 AGL	II	2	50
BESC'15	Netherlands (Bonaire, St. Eustatius and Saba)	-	0.72-2.0	1.25	600	10 AGL	0	1	50
BK'17	Denmark (Faroe Islands)	23-63	-	1.25	600	6/10/16/30 AGL	-	1	50
BNbD 20-04'17	Mongolia	19-33	-	1.22	600	10 AGL	A	1/2	5
BNS CP 28'81	St. Kitts and Nevis	64	-	1.23	3	10 AGL	1	1	50
	Trinidad and Tobago	52-58	-						
BNS DPC'10	Antigua and Barbuda	57	-	1.23	3	10 AGL	1	1	50
	Dominica	56	-						
	Grenada	54	-						
	St. Kitts and Nevis	58	-						
	St. Lucia	55	-						
	St. Vincent and the Grenadines	55	-						
	United Kingdom (Anguilla, Montserrat, Virgin Islands)	57-60	-						

Note: τ , ρ , R_{ref} , AGL and ASL denote averaging time, air density, return period, above ground level and above sea level, respectively.

Table 5.1 Specifications of reference wind speeds defined in 164 codes and standards (cont'd)

Code/standard	Country	U_{ref} (m/s)	q_{ref} (kN/m ²)	ρ (kg/m ³)	τ (s)	z (m) and level	Roughness		R_{ref} (yrs)
							Category	ISO	
BNS TR 28'13	Barbados	58	-	1.23	3	10 AGL	I	1	50
BOS 536-3'14	Botswana	-	-	1.2	600	10 AGL	B	2	50
BS CP3 CV'52	Guyana	20-32	-	1.23	60	12.2 ASL	D	1	-
	Pakistan	20-32	-						
BS CP3 CV2'70	Ghana	29-45	-	1.23	3	10 AGL	I	1	50
BS CP3 CV2'72	Mauritius	67	-	1.23	3	10 AGL	I	1	50
	Seychelles	27	-						
	Tanzania	27-48	-						
	Singapore	33	-						
	Sri Lanka	34-49	-						
	United Kingdom (Gibraltar, Jersey)	44-47	-						
BS 6399.2'97	Singapore	22	-	1.23	3600	10 ASL	country	2	50
	Bahrain	26	-						
	Qatar	25	-						
	United Kingdom (Wales)	20-25	-						
	United Kingdom (Falkland Islands)	30	-						
BS EN NA'10	Qatar	27	-	1.23	600	10 ASL	I/II	2	50
	United Kingdom (England, Northern Ireland, Scotland, Isle of Man)	22-31	-						
BSLN 1454'00	Japan	30-46	-	1.2	600	10 AGL	II	2	50
BSSKP'ND	North Korea	-	0.2-0.9	1.25	600	-	-	-	30
CAS 160.2'77	Zimbabwe	35	-	1.23	3	10 AGL	I	1	50
CES 145'15	Ethiopia	22	-	1.25	600	10 AGL	II	2	50
CH 2.01.05'19	Belarus	22-24	-	1.25	600	10 AGL	II	2	50
CHOC'08	Honduras	28-56	-	1.23	fastest-mile	10 AGL	C	2	50
CIC 103'12	Bolivia (Santa Cruz de la Sierra)	43	-	1.23	3	10 AGL	C	2	50
CIRSOC 102'05	Argentina	36-66	-	1.23	3	10 AGL	C	2	50
CNR DT 207'08	Italy	25-31	-	1.25	600	10 ASL	C	2	50
COVENIN 2003'89	Venezuela	19-29	-	1.23	fastest-mile	10 AGL	C	2	50
CPWEHK'19	China (Hong Kong)	60	-	1.2	3600	500 AGL	I	1	50
CR 1-1-4'12	Romania	-	0.4-0.7	1.25	600	10 AGL	II	2	50
CSN EN NA'13	Czech	23-36	-	1.25	600	10 AGL	II	2	50
CSP'89	Andorra	-	1.0-1.25	1.23	instantaneous	10 AGL	-	-	2.7
CTE DB-SE-AE'09	Spain	26-29	-	1.25	600	10 AGL	III	2	50
CUBiC'85	Guyana	20	0.25	1.2	600	10 AGL	2	2	50
	Antigua and Barbuda	40	-						
	Dominica	39	-						
	Grenada	38	-						
	St. Kitts and Nevis	40	-						
	St. Lucia	38	-						
	St. Vincent and the Grenadines	38	-						
	United Kingdom (Anguilla, Montserrat, Virgin Islands)	40-42	-						
CYS EN NA'10	Cyprus	24-40	-	1.25	600	10 AGL	II	2	50
DIN EN NA'10	Germany	23-30	-	1.25	600	10 AGL	II	2	50
DPT 1311-50'07	Thailand	25-30	-	1.25	3600	10 AGL	A	1/2	50
DS EN NA'15	Denmark	24-27	-	1.25	600	10 AGL	II	2	50
DSTU EN NA'10	Ukraine	25-31	-	1.25	600	10 AGL	II	2	50
DTR RNV'13	Algeria	25-31	0.38-0.58	1.2	600	10 AGL	II	2	50
DUWC'13	United Arab Emirates (Dubai)	30	-	1.25	600	10 AGL	II	2	50
ECP-201'12	Egypt	30-42	-	1.25	3	10 AGL	A	1/2	50
EKS 11'19	Sweden	21-26	-	1.25	600	10 AGL	II	2	50
ELOT EN NA'10	Greece	27-33	-	1.25	600	10 AGL	II	2	50
EN'05	South Africa	28-36	-	1.25	600	10 AGL	II	2	50
	Botswana	-	-						
	Turkey	28	-						
	Malta	28	-						
	Spain	26-29	-						
EPN-ENV 1.2.6'96	Estonia	21	-	1.25	600	10 AGL	II	2	50
EVS EN NA'07	Estonia	21	-	1.25	600	10 AGL	II	2	50
FLK'95	Denmark (Greenland)	36-51	-	1.85	600	10 AGL	open terrain	2	50
GB 50009'12	China	-	0.3-1.85	1.25	600	10 AGL	B	2	50
GL EN NA'10	Denmark (Greenland)	35-49	-	2.00	600	10 AGL	II	2	50
GS 1207'18	Ghana	29-45	-	1.23	3	10 AGL	I	1	50

Note: τ , ρ , R_{ref} , AGL and ASL denote averaging time, air density, return period, above ground level and above sea level, respectively.

Table 5.1 Specifications of reference wind speeds defined in 164 codes and standards (cont'd)

Code/standard	Country	U_{ref} (m/s)	q_{ref} (kN/m ²)	ρ (kg/m ³)	τ (s)	z (m) and level	Roughness		R_{ref} (yrs)
							Category	ISO	
HRN EN NA'14	Croatia	20-48	-	1.2	600	10 AGL	II	2	50
IS 875.3'87	India	33-55	-	1.2	3	10 AGL	2	2	50
	Bhutan	44	-						
	Nepal	47-55	-						
IS 875.3'15	India	33-55	-	1.2	3	10 AGL	2	2	50
IS EN NA'13	Ireland	25-28	-	1.23	600	10 ASL	I/II	2	50
ISIRI 519'96	Iran	35	-	-	-	10 AGL	-	-	-
IST EN NA'10	Iceland	36	-	1.25	600	10 AGL	II	2	50
IYBRY-V'09	Turkey (Istanbul)	25	-	1.25	600	10 AGL	II	2	50
KDS 41 10 15'19	South Korea	25-45	-	1.25	600	10 AGL	C	2	100
KMK 2.01.07'96	Uzbekistan	-	0.38-0.48	1.22	600	10 AGL	A	1/2	5
KTP 7'78	Albania	25-31	-	1.23	-	10 AGL	-	-	-
LST EN NA'12	Lithuania	24-32	-	1.25	600	10 AGL	II	2	50
LDVE'23	Costa Rica	28-39	-	1.27	3	10 AGL	C	2	50
LU EN NA'11	Luxembourg	24	-	1.25	600	10 AGL	II	2	50
LVS EN NA'11	Latvia	21-27	-	1.25	600	10 AGL	II	2	50
MBO 301'15	Iraq	33-44	-	1.23	3	10 AGL	a	1	50
MEST EN NA'16	Montenegro	20-40	-	1.23	600	10 AGL	II	2	50
MKC U.C7'91	North Macedonia	19-26	-	1.22	3600	10 AGL	B	2	50
MKC EN NA'20	North Macedonia	14-29	-	1.25	600	10 AGL	II	2	50
MNS 3177'81	Mongolia	-	0.27-0.7	1.25	-	10 AGL	-	-	-
MRDPW'04	Bulgaria	-	0.23-0.6	1.22	600	10 AGL	A	1/2	50
MS 1553'02	Malaysia	33-34	-	1.23	3	10 AGL	2	2	50
MS 820'10	Malawi	40	-	1.2	3	10 AGL	2	2	50
MSZ EN NA'07	Hungary	24	-	1.25	600	10 AGL	II	2	50
NB 1225003'14	Bolivia	8-68	-	1.23	3	10 AGL	C	2	50
NBCBD'15	Bangladesh	41-80	-	1.23	3	10 AGL	B	2	50
NBCCA'10/'15	Canada	-	0.3-1.23	1.29	3600	10 AGL	A	1/2	50
NBCIN'05	India	33-55	-	1.2	3	10 AGL	2	2	50
NBCIN'16	India	33-55	-	1.2	3	10 AGL	2	2	50
NBCJO'06	Jordan	33	-	1.23	3600	10 ASL	country	2	50
NBCMM'20	Myanmar	36-63	-	1.23	3	10 AGL	C	2	50
NBCNG'06	Nigeria	31-49	-	-	-	-	-	-	-
NBN EN NA'10	Belgium	23-26	-	1.25	600	10 AGL	II	2	50
NBR 6123'13	Brazil	30-50	-	1.23	3	10 AGL	II	2	50
NBRIR-6'13	Iran	22-36	-	1.23	3600	10 AGL	1	1/2	50
NC 285'03	Cuba	-	0.9-1.3	1.23	-	10 AGL	A	1/2	50
NCh 432'71	Chile	-	1.3	1.23	600	280/400/ 500 AGL	-	-	-
NCh 432'10	Chile	30-55	-	1.23	3	10 AGL	C	2	50
NCP 001-3'73	Nigeria	31-54	-	-	-	-	open country	2	-
NEC-SE-CG'14	Ecuador	21	-	1.23	instantaneous	10 AGL	A	1/2	-
NEN EN NA'11	Netherlands (Mainland)	25-30	-	1.25	600	10 AGL	-	2	50
NF EN NA'08&'12	Lebanon	26	-	1.23	600	10 AGL	II	2	50
	France (Metropolitan, Overseas regions and departments, St. Pierre and Miquelon, New Caledonia)	17-36	-						
NP 196'91	Paraguay	40-55	-	1.23	3	10 AGL	II	2	50
NP EN NA'10	Portugal	27-30	-	1.25	600	10 AGL	II	2	50
NS 02-058'08	Senegal	36-52	1.1-1.7	1.23	instantaneous	10 AGL	normal	2	-
NS EN NA'09	Norway	22-33	-	1.25	600	10 AGL	II	2	50
NSCP C101'15	Philippines	42-69	-	1.23	3	10 AGL	C	2	50
NSR'10	Colombia	17-36	-	1.23	3	10 AGL	C	2	-
NTC'18	Italy	25-31	-	1.25	600	10 ASL	C	2	50
	Holy See	27	-						
	San Marino	27	-						
NTCV'17	Mexico (Mexico City)	25-35	-	1.24	3	10 AGL	R2	2	50
NTDV'97	El Salvador	-	0.29	1.22	-	10 AGL	B	3	-
NV 65'76/'87	Morocco	39-62	-	1.23	instantaneous	10 AGL	normal	2	50
	Congo-Kinshasa	-	0.70-1.05						
	Tunisia	-	0.88-1.6						
	France (French Polynesia)	57	-						
NV 65'00/'09	Madagascar	46-97	1.3-5.9	1.23	instantaneous	10 AGL	normal	2	50
	Lebanon	35	-						
	France (Metropolitan, Overseas regions and departments, St. Martin)	38-59	0.88-2.1						
	Cameroon	29-38	-						

Note: τ , ρ , R_{ref} , AGL and ASL denote averaging time, air density, return period, above ground level and above sea level, respectively.

Table 5.1 Specifications of reference wind speeds defined in 164 codes and standards (cont'd)

Code/standard	Country	U_{ref} (m/s)	q_{ref} (kN/m ²)	ρ (kg/m ³)	τ (s)	z (m) and level	Roughness		R_{ref} (yrs)
							Category	ISO	
NZS 4203'84	Samoa	57	-	1.23	3	10 AGL	I	1	50
ONORM EN NA'13	Austria	-	0.19-0.5	1.25	600	10 AGL	II	2	50
OWAW'81	Netherlands (Aruba)	24	-	1.25	3600	10 AGL	I	1	50
PN EN NA'10	Poland	22-26	0.3-0.42	1.25	600	10 ASL	II	2	50
PNGS 1001.3'82	Papua New Guinea	24-36	-	1.2	3	10 AGL	2	2	50
RAVE'80	Dominican Republic	29-50	-	1.23	-	10 AGL	-	-	-
RAVE'01	Dominican Republic	50-67	-	1.2	3	10 AGL	C	1/2	50
RCTB'75	Mexico (Tabasco State)	36	-	1.27	-	-	-	-	50
RNC'07	Nicaragua	30-56	-	1.24	3	10 AGL	R2	2	50
RNE'06	Peru	8-36	-	1.27	-	10 AGL	-	-	50
RS 144-2'11	Rwanda	30-43	-	1.25	3600	10 AGL	II	2	50
RSA'83	Portugal	25-28	-	1.23	600	10 AGL	II	1/2	50
	Mozambique	25-28	-						
	Cabo Verde	25-28	-						
RSAREP'96	China (Macau)	46	-	1.23	-	10 AGL	I	1	200
RSAREP'08	China (Macau)	72	3.1	1.2	3	250 AGL	sea	1	50
RSEP'61	Mozambique	35	0.74	1.23	-	15 AGL	normal	2/3/4	3.3-5
SABC 301'18	Saudi Arabia	42-53	-	1.23	3	10 AGL	B	2	-
SANS 10160-3'18	South Africa	32-44	-	1.2	3	10 AGL	B	2	50
SCBWRD'14	China (Taiwan)	28-65	-	1.18	600	10 AGL	C	1/2	50
SFS EN NA'10&'16	Finland	21	-	1.25	600	10 AGL	II	2	50
SI 414'08	Israel	24-36	-	1.25	600	10 AGL	II	2	50
SIA 261'14	Switzerland	-	0.9-3.3	1.2	3	10 AGL	III	2/3	50
SIST EN NA'08	Slovenia	20-40	-	1.25	600	10 AGL	II	2	50
SLS EN NA'16	Sri Lanka	23-35	-	1.25	600	10 AGL	II	2	50
SM EN NA'18	Moldova	-	0.5-1	1.25	600	10 AGL	II	2	50
SN EN NA'16	Switzerland	-	0.9-3.3	1.2	3	10 AGL	III	2/3	50
SN RK EN NA'11	Kazakhstan	-	0.3-0.6	1.25	600	10 AGL	II	2	5
SNI 03-1727'89	Indonesia	25-40	-	1.23	-	-	-	-	-
SNI 1727'13	Indonesia (Jakarta)	39	-	1.23	3	10 AGL	C	2	-
SNI P 2.01.07'88/'05	Kyrgyzstan	-	0.23-0.48	1.22	600	10 AGL	A	1/2	5
	Tajikistan	-	0.3-0.38						
	Georgia	-	0.23-0.85						
	Moldova	-	0.3-0.38						
	Armenia	21-38	-						50
SP 20.13330'16	Russia	-	0.17-0.85	1.22	600	10 AGL	A	1/2	50
SP 201.1325800'14	Russia	20-44	-	1.25	600	10 AGL	2	2	50
SR EN NA'07	Romania	27-35	-	1.25	600	10 AGL	II	2	50
SRPS EN NA'17	Serbia	19-29	-	1.25	600	10 AGL	II	2	50
SS EN NA'09	Singapore	20	-	1.19	600	10 AGL	2	2/3/4	50
STN EN NA'10	Slovakia	24-33	-	1.25	600	10 AGL	II	2	50
STR 2.05.04'03	Lithuania	-	0.36-0.64	1.25	600	10 AGL	A	1/2	50
TCVN 2737'96	Vietnam	-	0.55-1.85	1.23	3	10 AGL	B	2	20
TCVN 2737'20	Vietnam	-	0.65-1.85	1.23	3	10 AGL	B	2	20
TGK 2.01.07'05	Turkmenistan	-	0.38-0.48	1.22	600	10 AGL	A	1/2	5
TPV'64	Bosnia and Herzegovina	-	0.45-1.1	1.25	3600	10 AGL	exposed	1	10
	Montenegro	-	0.45-1.1						
TS 498'97	Turkey	28	0.5	1.25	-	8 AGL	-	-	50
UBC'88	Palau	51	-	1.23	fastest-mile	9.1 AGL	C	2	50
UBC'97	Pakistan	33-36	-	1.23	fastest-mile	10 AGL	C	2	50
	Lebanon	38	-						
UNI EN NA'13	Italy	25-31	-	1.25	600	10 ASL	C	2	50
UNIT 50-84'94	Uruguay	39-44	-	1.2	3	10 AGL	I	1	20

Note: τ , ρ , R_{ref} , AGL and ASL denote averaging time, air density, return period, above ground level and above sea level, respectively.

Table 5.2 Special notes on reference wind speed specifications considered in Table 5.1

Code/standard	Country	Notes (Reference, etc.)
AS 1170.2'89	Australia (Norfolk Island)	AS/NZS 1170.2'02/'11
	New Zealand (Niue)	NBCNU'90
ASCE 7'05	Kuwait	Conversions into averaging time defined in ASCE 7'05
BOS 536-3'14	Botswana	Estimations needed from annual wind roses
BS 6399.2'97	Bahrain	A consulted value with authorities (see Chapter 2)
	United Kingdom (Falkland Islands)	A recommended value by authorities (see Chapter 2)
EN'05	South Africa	SANS 10160-3'11
	Botswana	BOS 536-3'14
	Spain	CTE DB-SE-AE'09
	Malta	A recommended value by authorities (see Chapter 2)
IS 875.3'87	Bhutan	BTS-002'03
NV 65'76/'87	Cameroon	Values that have been commonly adopted in the country (see Chapter 2)
	Congo-Kinshasa	
	Tunisia	
RSA'83	Mozambique	Same approach as used in Portugal
	Cabo Verde	
RSEP'61	Mozambique	Same approach as used in Portugal
	Cabo Verde	
SNI 1727'13	Indonesia (Jakarta)	A consensus value among authorities (see Chapter 2)
UBC'97	Pakistan	BCP SP'07

Table 5.3 Summary of reference wind speed specifications

Conditions		Specifications
(1)	Averaging time τ	<ul style="list-style-type: none"> - Instantaneous - 3, 20 (with a conversion factor to 3 seconds), 60 (including fastest-mile), 600 or 3600 seconds - No definition
(2)	Height z and level	<ul style="list-style-type: none"> - 10 m above ground (AGL) - 10 m above the sea (ASL) - 250 m AGL, 500 m AGL, 12.2 m ASL - No definition
(3)	Ground roughness	<ul style="list-style-type: none"> - Sea - Countryside: Level ground with few obstructions - Outskirts: Level ground with some obstructions - No definition
(4)	Return Period R_{ref}	<ul style="list-style-type: none"> - 50 years - 5 years, 20 years, or 100 years - Multiple return periods (5, 50, 100, 500, 700, 1,000, 1,300 years, etc.)
(5)	Air density ρ	<ul style="list-style-type: none"> - 1.18 to 1.29 kg/m³ - 1.85 or 2.00 kg/m³ (Greenland)

5.2.2 Wind speed profile

Wind speed profile $K_u(z)$ is a measure of the magnitude of $\bar{U}(z)$ relative to U_{ref} . Table 5.4 organizes specifications of $K_u(z)$ in reference terrain roughness defined in 113 codes and standards, which provide $K_u(z)$, $I_u(z)$, $S_u(z, n)$, and $L_u(z)$ in mathematical forms. In practical use, $K_u(z)$ is defined by expressions such as logarithmic, power, stepwise, or polygonal functions. Some profiles also combine these functions. Many codes and standards define a power exponent from 0.14 to 0.17 in reference terrain roughness. However, four standards: BNS CP 28'81, BNS DPC'10, BNS TR 28'13, and TCVN 2737'96 and two standards: SIA 261'14 and SN EN NA'16 define it as 0.09 or 0.10 and 0.23, respectively. Furthermore, many codes and standards define a roughness length as 0.01, 0.02, or 0.05 in reference terrain roughness except that one standard: RSAEEP'08 and two standards: SIA 261'14 and SN EN NA'16 define it as 0.0037 and 0.3, respectively. These differences are due to differences in the specifications of reference wind speeds.

Most codes and standards define $K_u(z)$ for some terrain roughness categories. Figure 5.2(a) illustrates five typical profiles up to $z=200$, which are those of ECP-201'12, ANSI A58.1'82, EN'05, SIA 261'14, and AS/NZS 1170.2'11. The higher the terrain roughness, the lower the $K_u(z)$ at the same height, and the higher the roughness heights and the gradient heights. Here, "roughness height" means the height AGL below which $K_u(z)$, $I_u(z)$, or $L_u(z)$ is considered constant due to too strong effects of terrain roughness, and "gradient height" means the height AGL above which $K_u(z)$, $I_u(z)$, or $L_u(z)$ is considered constant due to well weakened effects of terrain roughness. Representative examples are EN'05 and ASCE 7'16, which define $K_u(z)$ as logarithmic and power functions, respectively. However, although ASCE 7'16 defines gradient heights above $z=200$, EN'05 does not define any gradient heights. ECP-201'12 defines $K_u(z)$ as stepwise functions with the same value at roughness heights or less. However, it has unclear gradient heights regardless of terrain roughness. ANSI A58.1'82 defines $K_u(z)$ as power functions with the same roughness height. It also has gradient heights above $z=200$ regardless of terrain roughness. SIA 261'14 defines $K_u(z)$ as power functions with gradient heights above $z=200$. However, $K_u(z)$ for the highest terrain roughness of four categories, forms a stepwise profile that connects to $K_u(z)$ of the second highest at a specific height. AS/NZS 1170.2'11 defines $K_u(z)$ as polygonal functions with gradient heights above $z=200$, which are divided into two types of profiles: non-cyclonic storms (solid black lines) and cyclonic storms (dashed red lines). For cyclonic storms, it defines $K_u(z)$ of the lowest and second lowest terrain roughnesses of four categories as the same profile. This is also true for the third lowest above a specific height. On the other hand, BS EN NA'10 does not define $K_u(z)$ based on terrain roughness. Instead, it provides charts for quantifying the surrounding situation of a target site from distances to the sea and edges of town as well as the average height of upwind buildings to calculate $K_u(z)$.

Table 5.4 Specifications of components describing atmospheric boundary layers in 113 codes and standards

Code/standard	T (s)	$K_u(z)$			$I_u(z)$			Type of $S_u(z,n)$	$L_u(z)$	
		Law	ε	z_0 (m)	Law	ε	z_0 (m)		Law	ε
AGIES NSE 2'10	3600	power	0.14	-	power	0.14	-	Davenport	-	-
AIJ-RLB'15	600	power	0.15	-	power	0.20	-	Karman	power	0.50
AS 1170.2'89	3600	polygonal	-	0.02	polygonal	-	0.02	Harris	power	0.25
AS/NZS 1170.2'02/'11	3600	polygonal	-	0.02	polygonal	-	0.02	Karman	power	0.25
ASC'12	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
ASCE 7'88	3600	power	0.14	-	power	0.14	-	Davenport	-	-
ASCE 7'02/'05	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
ASCE 7'10	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
ASCE 7'16	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
AzDTN 2.1-1'15	600	power	0.15	-	power	0.15	-	Davenport	-	-
BAS EN NA'18	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
BCP SP'07	3600	power	0.14	-	power	0.14	-	Davenport	-	-
BDS EN NA'11	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
BESC'15	3600	power	0.10	-	power	0.10	-	Davenport	-	-
BNbD 20-04'17	600	power	0.15	-	power	0.15	-	Davenport	-	-
BNS CP 28'81	3600	power	0.10	-	power	0.10	-	Davenport	-	-
BNS DPC'10	3600	power	0.10	-	power	0.10	-	Davenport	-	-
BNS TR 28'13	3600	power	0.10	-	power	0.10	-	Davenport	-	-
BS EN NA'10	600	polygonal	-	0.01/0.05	polygonal	-	0.01/0.05	Kaimal	power	0.44/0.52
BSLN 1454'00	600	power	0.15	-	power	0.20	-	Karman	power	0.50
CES 145'15	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
CH 2.01.05'19	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
CHOC'08	3600	power	0.14	-	power	0.14	-	Davenport	-	-
CIC 103'12	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
CIRSOC 102'05	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
CNR DT 207'08	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
COVENIN 2003'89	3600	power	0.14	-	power	0.14	-	Davenport	-	-
CR 1-1-4'12	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
CSN EN NA'13	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
CYS EN NA'10	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
DIN EN NA'10	600	power	0.16	-	power	0.16	-	Kaimal	power	0.26
DPT 1311-50'07	3600	power	0.14	-	power	0.14	-	Davenport	-	-
DS 410'82	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	linear & constant	-
DS EN NA'15	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
DSTU EN NA'10	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
DTR RNV'13	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
DUWC'13	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
ECP-201'12	3600	stepwise	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
EKS 11'19	600	logarithm	-	0.05	logarithm	-	0.05	Karman	constant	-
ELOT EN NA'10	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
EN'05	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
EPN-ENV 1.2.6'96	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.26
EVS EN NA'07	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
GB 50009'12	600	power	0.15	-	power	0.15	-	Davenport	-	-
GL EN NA'10	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
HRN EN NA'14	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
IS 875.3'15	3600	logarithm	-	0.02	logarithms	-	0.02	Karman	power	0.25
IS EN NA'13	600	polygonal	-	0.01/0.05	polygonal	-	0.01/0.05	Kaimal	power	0.44/0.52
IST EN NA'10	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
IYBRY-V'09	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
KDS 41 10 15'19	600	power	0.15	-	power	0.20	-	Karman	power	0.50
KMK 2.01.07'96	600	polygonal	-	-	polygonal	-	-	Davenport	-	-
LST EN NA'12	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
LDVE'23	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
LU EN NA'11	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
LVS EN NA'11	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
MEST EN NA'16	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
MKC EN NA'20	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
MRDPW'04	600	power	0.15	-	power	0.15	-	Davenport	-	-
MS 1553'02	3600	polygonal	-	0.02	polygonal	-	0.02	Harris	power	0.25
MSZ EN NA'07	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
NB 1225003'14	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
NBCBD'15	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
NBCCA'10/'15	3600	power	0.14	-	power	0.14	-	Davenport	-	-
NBCIN'16	3600	logarithm	-	0.02	logarithms	-	0.02	Karman	power	0.25
NBCMM'20	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
NBN EN NA'10	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52

Note: ε and z_0 denote power exponent and roughness length, respectively.

Table 5.4 Specifications of components describing atmospheric boundary layers in 113 codes and standards (cont'd)

Code/standard	T (s)	$K_u(z)$			$I_u(z)$			Type of $S_u(z, n)$	$L_u(z)$	
		Law	ε	z_0 (m)	Law	ε	z_0 (m)		Law	ε
NBR 6123'13	600	power	0.15	-	power	0.15	-	Harris	-	-
NBRIR-6'13	3600	power	0.14	-	power	0.14	-	Davenport	-	-
NCh 432'10	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
NEN 6702'07	3600	logarithm	-	0.03	logarithm	-	0.03	Davenport	-	-
NEN EN NA'11	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
NF EN NA'08&'12	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
NP EN NA'10	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
NS EN NA'09	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
NSCP C101'15	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
NSR'10	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
NT 30.185'04	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.26
NTCV'17	600	power	0.16	0.05	power	0.16	0.05	Kaimal	power	0.52
ONORM EN NA'13	600	power	0.15	-	power	0.15	-	Kaimal	power	0.52
PMN EN NA'20	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
PN EN NA'10	600	power	0.17	-	logarithm	-	0.05	Kaimal	power	0.52
PNGS 1001.3'82	3600	power	0.15	-	power	0.15	-	Davenport	power	0.15
RSAREP'08	3600	logarithm	-	0.0037	power	0.14	-	Karman	power	0.39
SABC 301'18	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
SCBWRD'14	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
SFS EN NA'10&'16	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
SI 414'08	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
SIA 261'14	600	power & stepwise	0.23	0.30	power & stepwise	0.23	0.30	Kaimal	-	-
SIST EN NA'08	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
SLS EN NA'16	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
SM EN NA'18	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
SN EN NA'16	600	power & stepwise	0.23	0.30	power & stepwise	0.23	0.30	Kaimal	-	-
SN RK EN NA'11	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
SNI 1727'13	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
SNiP 2.01.07'88/'05	600	polygonal	-	-	polygonal	-	-	Davenport	-	-
SP 20.13330'16	600	power	0.15	-	power	0.15	-	Davenport	-	-
SP 201.1325800'14	600	power	0.15	0.05	power	0.15	0.05	Davenport	-	-
SR EN NA'07	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
SRPS EN NA'17	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
SS EN NA'09	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
STN EN NA'10	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52
STR 2.05.04'03	600	polygonal	-	-	polygonal	-	-	Davenport	-	-
TCVN 2737'96	3	power	0.09	-	power	0.09	-	Davenport	-	-
TCVN 2737'20	3600	power	0.15	-	power	0.17	-	Kaimal	power	0.20
TGK 2.01.07'05	600	polygonal	-	-	polygonal	-	-	Davenport	-	-
UBC'88	3600	power	0.14	-	power	0.14	-	Davenport	-	-
UBC'97	3600	power	0.14	-	power	0.14	-	Davenport	-	-
UNI EN NA'13	600	logarithm	-	0.05	logarithm	-	0.05	Kaimal	power	0.52

Note: ε and z_0 denote power exponent and roughness length, respectively.

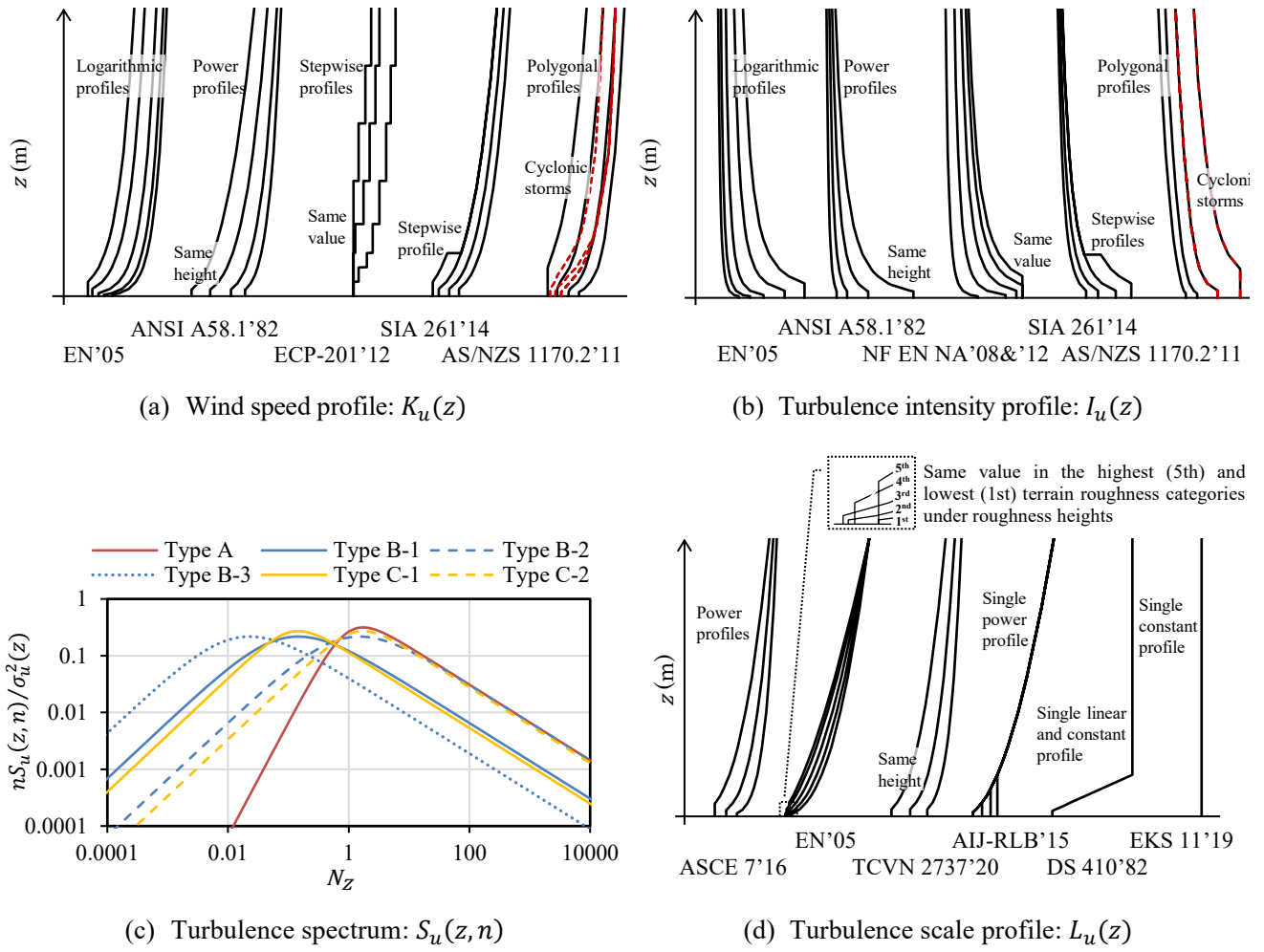


Figure 5.2 Typical examples of components describing atmospheric boundary layers

5.2.3 Turbulence intensity profile

Turbulence intensity profile $I_u(z)$ is a measure of the magnitude of $u(z, \tau, T)$ relative to $\bar{U}(z)$. Table 5.4 also organizes specifications of $I_u(z)$ defined in 113 codes and standards. In practical use, $I_u(z)$ is defined by expressions such as $K_u(z)$. Although most codes and standards define power exponents or roughness lengths to be the same as those of $K_u(z)$, three codes and standards: AIJ-RLB'15, BSLN 1454'00, and KDS 41 10 15'19 define power exponents to be slightly different from that of $K_u(z)$.

Most codes and standards define $I_u(z)$ for some terrain roughness categories, as is the case with $K_u(z)$. Figure 5.2(b) illustrates five typical profiles up to $z=200$, which are those of ANSI A58.1'82, EN'05, NF EN NA'08&'12, SIA 261'14, and AS/NZS 1170.2'11. The higher the terrain roughness, the higher the $I_u(z)$ at the same height, and the higher the roughness heights and the gradient heights. Representative examples are EN'05 and ASCE 7'16, which define $I_u(z)$ with similar expressions and characteristics to those of $K_u(z)$. That is true for ANSI A58.1'82 and SIA 261'14. BS EN NA'10 also gives charts in the same way as for $K_u(z)$. On the other hand, AS/NZS 1170.2'11 defines $I_u(z)$ as four polygonal functions for a total of eight types of profiles, combining four terrain roughness categories with two storms. However, it defines $I_u(z)$ of the highest terrain roughness for cyclonic storms (dashed red lines) as that of the highest for non-cyclonic storms (solid black lines), and furthermore, $I_u(z)$ from the second to fourth highest terrain roughnesses for cyclonic storms as that of the third highest for non-cyclonic storms. NF EN NA'08&'12 defines $I_u(z)$ as logarithmic functions with the same profiles for the first and second highest terrain roughnesses of five categories at roughness heights or less. However, it does not define any gradient heights, as is the case with EN'05.

5.2.4 Turbulence spectrum

Turbulence spectrum $S_u(z, n)$, which is known as a spectral density function, is a measure of the magnitude of $u(z, \tau, T)$ at each n (Hz). In practical use, it is defined in a non-dimensional form as

$$\frac{nS_u(z, n)}{\sigma_u^2(z)} = \frac{aN_u^\gamma(z)}{(b + cN_u^\alpha(z))^\beta}, \quad (5.13)$$

$$N_u(z) = \frac{nL_u(z)}{U(z)}, \quad (5.14)$$

where $N_u(z)$ is non-dimensional frequency. Also, a , b , and c is called position factor, and α , β , and γ is called shape factor. Table 5.5 lists them. Of these, a , b , and c are normalized so that the area surrounded by $S_u(z, n)$, which corresponds to $\sigma_u^2(z)$, is 1. Turbulence spectra defined in 113 codes and standards are roughly divided into three types: A, B, and C according to β . Of these, two types, B and C, are divided into three subtypes B-1, B-2, or B-3 and two subtypes C-1 or C-2, respectively. Types A, B, C-1, and C-2 are commonly called the Davenport, Kaimal, Karman, and Harris spectra, respectively. Also, this table lists 37 representative groups, which are the sum of the numbers in parentheses: (), for each combination of $S_u(z, n)$ and T . Here, multiple representatives with the same $S_u(z, n)$ and T mean that each of them defines different $L_u(z)$.

Twenty-nine codes and standards adopt Type A, which was classified into eight representative groups:

NBCCA'05/'10/'15, ANSI A58.1'82/ASCE 7'88, NEN 6702'07, PNGS 1001.3'82, GB 50009'12, SNiP 2.01.07'88/'05/SP 20.13330'16, SP 201.1325800'14, and TCVN 2737'96. Sixty-nine codes and standards adopt Type B-1, which was classified into 19 representative groups: ECP-201'12, ASCE 7'98/'02/'05/'10/'16, LDVE'23, SCBWRD'14, TCVN 2737'20, NTCV'17, EN'05, ENV'95, PN EN NA'10, SFS EN NA'10&'16, NS EN NA'09, BS EN NA'10, UNI EN NA'12, NP EN NA'10, ONORM EN NA'13, NBN EN NA'10, NF EN NA'08&'12, DIN EN NA'10, and NEN EN NA'11. Three codes and standards adopt Types B-2 and B-3, which were grouped into two representative groups: FLK'95&DS 410'82 and SIA 261'14/SN EN NA'16, respectively. Nine codes and standards adopt Type C-1, which was classified into six representative groups: RSAEEP'08, IS 875.3'15/NBCIN'16, AS/NZS 1170.2'02/'11, AIJ-RLB'15, KDS 41 10 15'19, and EKS 11'19. Three codes and standards adopt Type C-2, which was classified into two representative groups: AS 1170.2'89 and NBR 6123'13.

Table 5.4 also organizes T in 113 codes and standards. It was identified based on the expected wind duration in the calculation process of dynamic responses of structures. These codes and standards define any of $T=3600$, 600, or 3. Each typical code or standard is ASCE 7'16, EN'05, and TCVN 2737'96. Only TCVN 2737'96 allows a 3-second sampling length to calculate dynamic responses of structures. Table 5.5 shows that for Type A, 17, 11, and 1 codes and standards define $T=3600$, 600, and 3, which are divided into 4, 3, and 1 representative groups, respectively. For Type B-1, 19 and 50 codes and standards define $T=3600$ and 600, which are divided into 5 and 14 representative groups, respectively. One and two standards, which adopt Types B-2 and B-3, respectively, define $T=600$ and both comprise one representative group. For Type C-1, five and four codes and standards define $T=3600$ and 600, respectively, which both consisted of three representative groups. For Type C-2, two and one standards define $T=3600$ and 600, which were divided into two and one representative groups, respectively.

Figure 5.3 to Figure 5.8 show on the world map countries that adopt spectral Types A, B-1, B-2, B-3, C-1, C-2, or spectral graphs. These figures individually show the status of small countries with less than 5,000 km². Countries defining Type B-1 spread across all five regions. Sweden is the only country defining Type C-1 other than countries in two regions: Asia and Oceania. Many of the countries defining Type A are in the Northern Hemisphere, and many of the countries defining Type C-2 are in the Southern Hemisphere. Three countries adopting IS 875.3'87: Bhutan, India, and Nepal and one country adopting NCh 432'71: Chile define turbulence spectra in graphs.

Figure 5.2(c) shows $nS_u(z, n)/\sigma_u^2(z)$ for $L_u(z)/\bar{U}(z)=1$. For Type B-3, however, z is substituted for $L_u(z)$. Here, lines colored red, blue, and yellow represent the spectral curves of Types A, B, and C, respectively. Also, solid, dashed, and dotted lines colored blue, and solid and dashed lines colored yellow represent those of Types B-1, B-2, B-3, C-1, and C-2, respectively. This figure shows that three spectra of Type B have the same spectral shape and peak value but different non-dimensional peak frequencies. It is true for two spectra of Type C. Peak values for Types A, B, and C are 0.31, 0.22, and 0.27, respectively. However, $N_u(z)$ at these points is 1.73 for Types A and C-2; 0.15 for Types B-1 and C-1; and 1.00 and 0.02 for Types B-2 and B-3, respectively. Additionally, $N_u(z)$ at the peak value of Type C-2 is 11.9 times that of Type C-1 and those of Types B-2 and B-3 are 6.8 and 0.15 times that of Type B-1, respectively.

Table 5.5 Specifications of turbulence spectra and representative groups for each spectral type

Type	$S_u(z, n)$						$T(s)$	Code/standard	
	a	b	c	α	β	γ		Total	Representative group (37)
A	2/3	1	1	2	4/3	2	3600	17	29 NBCCA'05/'10/'15, ANSI A58.1'82/ASCE 7'88, NEN 6702'07, PNGS 1001.3'82 (4) GB 50009'12, SNiP 2.01.07'88/'05/SP 20.13330'16, SP 201.1325 800'14 (3) TCVN 2737'96 (1)
							600	11	
							3	1	
B-1	6.8	1	10.3	1	5/3	1	3600	19	72 ECP-201'12, ASCE 7'98/'02/'05/'10/'16, LDVE'23, SCBWR D'14, TCVN 273 7'20 (5) NTCV'17, EN'05, ENV'95, PN EN NA'10, SFS EN NA'10&'16, NS EN NA'09, BS EN NA'10, UNI EN NA'13, NP EN NA'10, ONORM EN NA'13, NBN EN NA'10, NF EN NA'08&'12, DIN EN NA'10, NEN EN NA'11 (14) FLK'95&DS 410'82 (1) SIA 261'14/SN EN NA'16 (1)
							600	50	
							600	1	
B-2	1	1	1.5	2	5/6	1	600	2	12 RSAEEP'08, IS 875.3'15/NBCIN'16, AS/NZS 1170.2'02/'11 (3) AIJ-RLB'15, KDS 41 10 15'19, EKS 11'19 (3) AS 1170.2'89 (1) NBR 6123'13 (1)
B-3	44	1	66				600	1	
C-1	4	1	70.8	2	5/6	1	3600	5	12 RSAEEP'08, IS 875.3'15/NBCIN'16, AS/NZS 1170.2'02/'11 (3) AIJ-RLB'15, KDS 41 10 15'19, EKS 11'19 (3) AS 1170.2'89 (1) NBR 6123'13 (1)
C-2	0.34	1	0.5				600	4	
							3600	2	
							600	1	

Note: the numerical value in parentheses: () shows the number of representative groups with different $L_u(z)$

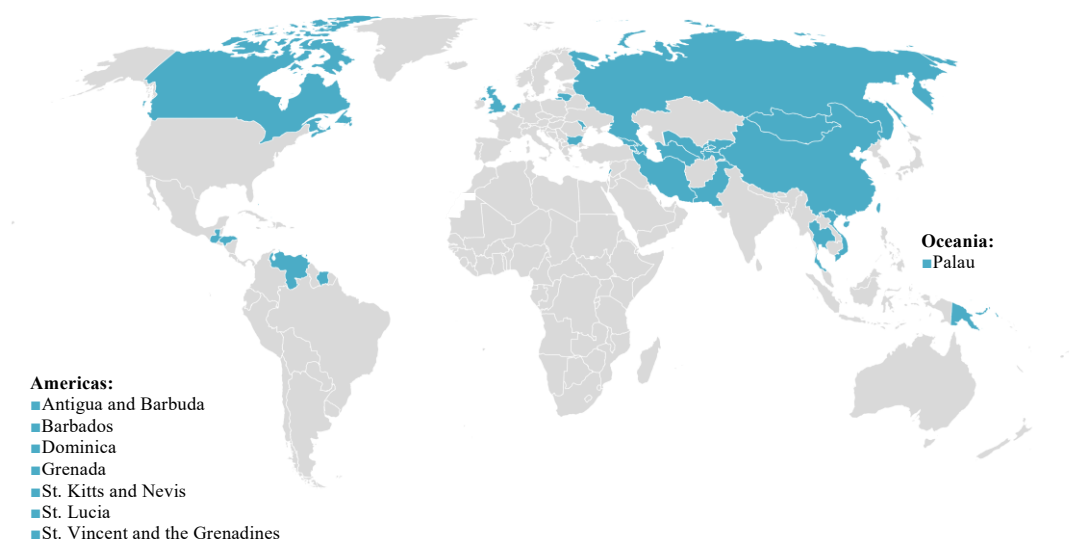


Figure 5.3 Distribution of countries adopting spectral Type A

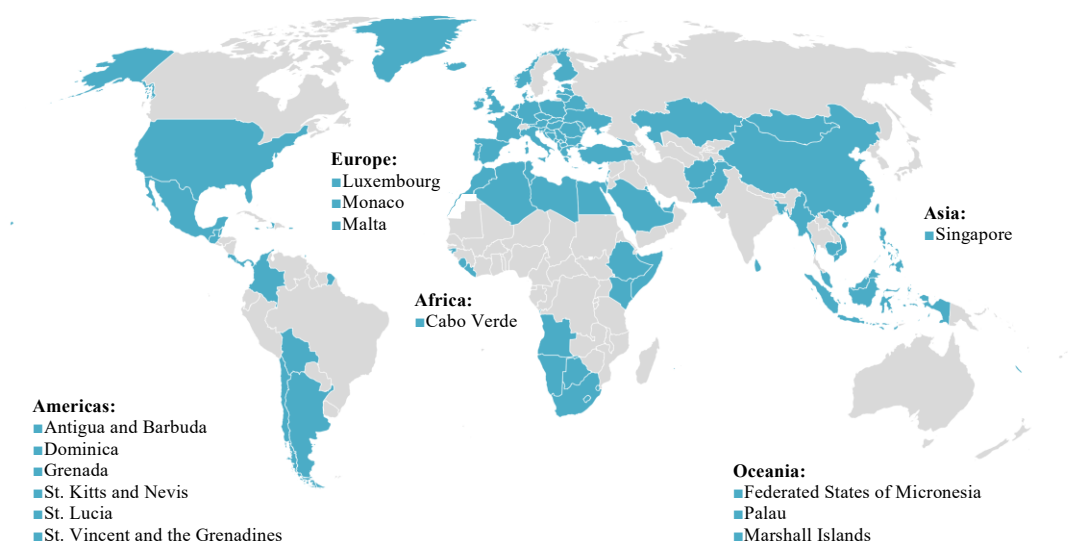


Figure 5.4 Distribution of countries adopting spectral Type B-1



Figure 5.5 Distribution of countries adopting spectral Types B-2 or B-3

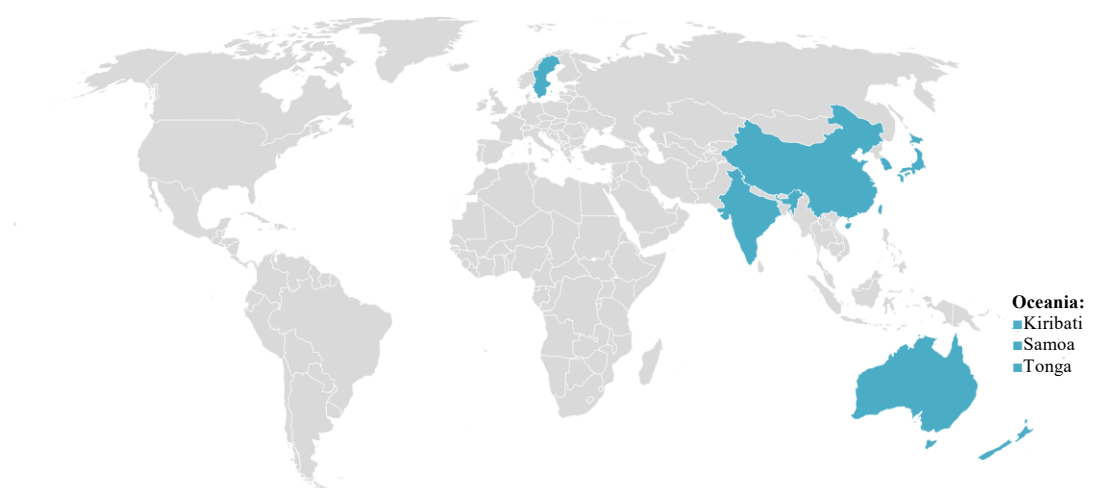


Figure 5.6 Distribution of countries adopting spectral Type C-1



Figure 5.7 Distribution of countries adopting spectral Type C-2

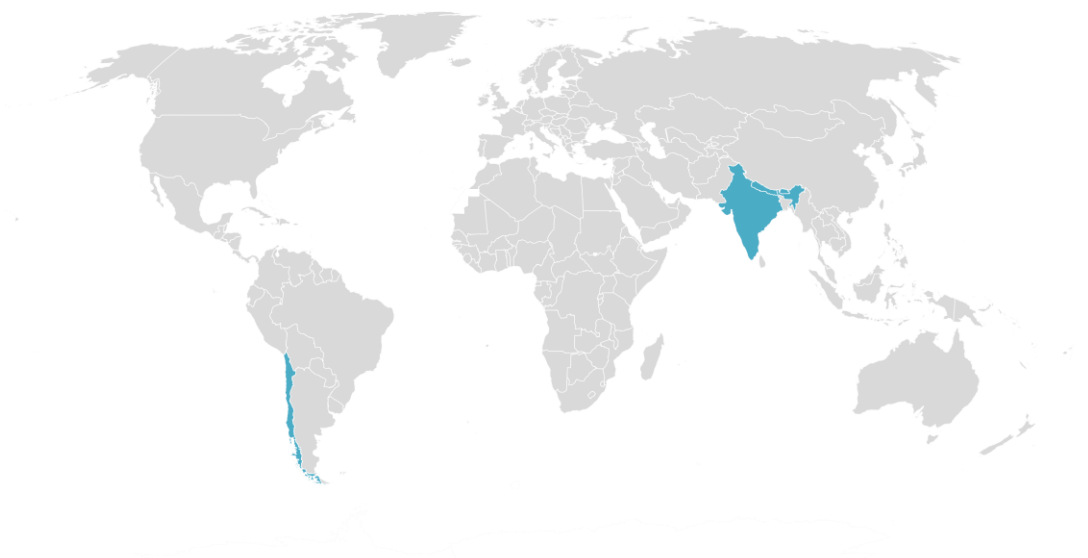


Figure 5.8 Distribution of countries adopting spectral graphs

5.2.5 Turbulence scale profile

Turbulence scale profile $L_u(z)$ is a measure of the size of the spatial spread of $u(z, \tau, T)$. $L_u(z)$ determines the peak frequency of $S_u(z, n)$. Table 5.4 also organizes specifications of $L_u(z)$ defined in 113 codes and standards. In practical use, $L_u(z)$ is defined by expressions such as power, logarithmic, linear, or constant functions. Some profiles also combine these functions. Codes and standards giving power functions define power exponents from 0.15 to 0.52 in reference terrain roughness.

Many codes and standards define $L_u(z)$ for some terrain roughness categories, similar to $K_u(z)$ or $I_u(z)$. Figure 5.2(d) illustrates six typical profiles up to $z=200$, which are those of ASCE 7'16, EN'05, TCVN 2737'20, AIJ-RLB'15, DS 410'82, and EKS 11'19. The higher the terrain roughness, the lower the $L_u(z)$ at the same height, and the higher the roughness heights and the gradient heights. The most representative example is ASCE 7'16, which defines $L_u(z)$ as power functions with different roughness heights and different gradient heights above $z=200$ for each terrain roughness. EN'05 also defines $L_u(z)$ as power functions but partially differs from those of ASCE 7'16 under roughness heights. EN'05 defines $L_u(z)$ of the highest terrain roughness of five categories as that of the lowest. A similar characteristic is true for ENV'95, which defines $L_u(z)$ of the highest terrain roughness of four categories as that of the second highest. In addition, neither EN'05 nor ENV'95 defines any gradient heights. TCVN 2737'20 defines $L_u(z)$ as power functions with the same roughness height regardless of terrain roughness but with different gradient heights above $z=200$. AIJ-RLB'15 defines $L_u(z)$ as a single power function with different roughness heights and different gradient heights above $z=200$ for each terrain roughness. DS 410'82 defines $L_u(z)$ as a single profile that connects a linear function to a constant function at a specific height regardless of terrain roughness. EKS 11'19 defines $L_u(z)$ as a single constant function independent of terrain roughness. Incidentally, IS 875.3'15/NBCIN'16 defines $L_u(z)$ of four categories as two power functions, which are divided into the highest and the second to fourth highest. BS EN NA'10 follows EN'05 but the definition in terrain roughness does not fully correspond to the definition for $K_u(z)$ or $I_u(z)$.

It should be noted the following points. Codes and standards such as NBCCA'05/'10/'15, ANSI A58.1'82/ASCE 7'88, and GB 50009'12, which adopt the spectral Type A, define characteristic scales at 10 m above ground or at building height instead of $L_u(z)$. NBR 6123'13, which adopts the spectral Type C-2, define the characteristic scale at 10 m above ground instead of $L_u(z)$. Additionally, two standards based on SIA 261'14 define $S_u(z, n)$ as a function of z without defining $L_u(z)$.

5.3 Peak Factors

Peak factor $g_u(z, \tau, T)$ is a measure of the contribution of the standard deviation of fluctuating wind speeds for T to the maximum wind speed averaged by τ . Additionally, $g_u(z, \tau, T)$ can be considered a safety factor in the probability distribution of fluctuating wind speeds. In this chapter, we compute $g_u(z, \tau, T)$ based on Section 5.1.

5.3.1 Computational cases

Eleven combinations of $S_u(z, n)$ and T : Types A, B-1, C-1, and C-2 for $T=3600$; Types A, B-1, B-2, B-3, C-1, and C-2 for $T=600$; and Type A for $T=3$ are considered computational cases, as shown in Table 5.6. In addition, because most of the 164 codes and standards require any of instantaneous wind speed, 3-second average wind speed (including 20-second average wind speed with conversion factor), 1-minute average wind speed (including fastest-mile wind speed), 10-minute average wind speed, or 1-hour average wind speed as U_{ref} or q_{ref} , let τ be 0.25, 3, 60, and 600 for $T=3600$; 0.25, 3, and 60 for $T=600$; and 0.25 for $T=3$. Of these, $\tau=0.25$ assumes instantaneous wind speeds, which are required by a certain number of codes and standards without $I_u(z)$, $S_u(z, n)$, or $L_u(z)$ as U_{ref} or q_{ref} .

Table 5.6 Computational cases for calculating peak factors

T (s)	Type	τ (s)			
		0.25	3	60	600
3600	A	✓	✓	✓	✓
	B-1	✓	✓	✓	✓
	C-1	✓	✓	✓	✓
	C-2	✓	✓	✓	✓
600	A	✓	✓	✓	-
	B-1	✓	✓	✓	-
	B-2	✓	✓	✓	-
	B-3	✓	✓	✓	-
	C-1	✓	✓	✓	-
	C-2	✓	✓	✓	-
3	A	✓	-	-	-

5.3.2 Computational conditions

Numerical integrations over semi-infinite intervals of $\sigma_u(z, \tau, T)$, $\rho_u(z, \tau, T)$, $\nu_u(z, \tau, T)$, and $\sigma_u(z)$, as well as $\hat{u}(z, \tau, T)/\sigma_u(z, \tau, T)$ follow double exponential formulas, which are typically performed using the trapezoidal rule. The integration ranges and step sizes are semi-automatically determined by iterative computations. Of these, the integration ranges, both high and low, are cut at points where the value of the integrand of $\hat{u}(z, \tau, T)/\sigma_u(z, \tau, T)$ is less than 0.0001. Moreover, the integration step sizes increase by 2^m ($m=1, 2, 3\dots$), until each truncation error satisfies the following equation:

$$|g_u^{m+1}(z, \tau, T) - g_u^m(z, \tau, T)| \leq 0.01. \quad (5.15)$$

5.3.3 Computational results

Figure 5.9 shows curves of $g_u(z, \tau, T)$ for 11 combinations, and furthermore Table 5.7 to Table 5.11 show their numerical data. In this figure, four solid lines colored red, blue, orange, and green represent $g_u(z, 0.25, T)$, $g_u(z, 3, T)$, $g_u(z, 60, T)$, and $g_u(z, 600, T)$, respectively. The circles show the Hino factors (Hino 1964), which adopt Type A, and the dashed lines show the Solari factors (Solari 1993) and ESDU factors (ESDU 2002), which adopt Types B-1 and C-1, respectively. These colors have the same meaning as the solid lines. Moreover, to supplement comparative data, for Type C-1 with $T=600$, two dashed lines colored black represent the Holmes factors (Holmes et al. 2014), whose upper and lower dashed lines represent $g_u(z, 0.17, 600)$ and $g_u(z, 0.5, 600)$, respectively. The double-headed arrow between two dotted lines represents the range of $L_u(z)/\bar{U}(z)$ calculated from $z=10$ to 200 (hereinafter referred to as “practical $L_u(z)/\bar{U}(z)$ ”), considering terrain roughness, U_{ref} , $K_u(z)$, and $L_u(z)$ of the codes or standards concerned. Table 5.12 lists the maximum and minimum of the practical $L_u(z)/\bar{U}(z)$ for each combination. However, NEN 6702'07 is not considered in Type A, because the country and overseas territory that adopt it do not define $\bar{U}(z)$ with the same T as it. Additionally, for Type B-3, z is substituted for $L_u(z)$.

This figure shows that all curves of $g_u(z, \tau, T)$ are convex upward for all T . The longer τ , the lower the maximum $g_u(z, \tau, T)$ and the higher the $L_u(z)/\bar{U}(z)$ at that point. For Type A, $g_u(z, 600, 3600)$ and $g_u(z, 60, 600)$ are a little smaller for high $L_u(z)/\bar{U}(z)$ than the Hino factors but consistent with the Hino factors for lower $L_u(z)/\bar{U}(z)$. This trend also applies to $g_u(z, \tau, 3)$. For Type B-1, $g_u(z, \tau, 3600)$ and $g_u(z, \tau, 600)$ deviate for high $L_u(z)/\bar{U}(z)$ from the Solari factors but have almost the same curvature as the Solari factors for the practical $L_u(z)/\bar{U}(z)$. The same trend is mainly true for the relationship of those for Type C-1 with $T=3600$ and the ESDU factors. For Type C-1 with $T=600$, $g_u(z, 0.25, 600)$ lies between two Holmes factors $g_u(z, 0.17, 600)$ and $g_u(z, 0.5, 600)$. For Type A, the difference from Hino for high $L_u(z)/\bar{U}(z)$ is due to the consideration of higher order terms in the asymptotic approximation of $\hat{u}(z, \tau, T)/\sigma_u(z, \tau, T)$. Additionally, for Type B-1 with $T=3600$, $g_u(z, \tau, T)$ based on the asymptotic approximation of $\hat{u}(z, \tau, T)/\sigma_u(z, \tau, T)$ has a maximum difference of 11% at $\tau=600$ within the range of practical $L_u(z)/\bar{U}(z)$ from that based on the numerical integration. However, the maximum difference is 1% at $\tau=0.25$ for the same case. The larger the τ/T and the higher the $L_u(z)/\bar{U}(z)$, the larger the difference. The asymptotic approximation is adequate for estimating $g_u(z, \tau, T)$ with small τ/T and low $L_u(z)/\bar{U}(z)$ such as strong gusts of wind.

Table 5.13 shows the maximum $g_u(z, \tau, T)$ for each τ . The number in parentheses [] shows $L_u(z)/\bar{U}(z)$ at that point. However, $L_u(z)$ is z for Type B-3. This table shows that the maxima of $g_u(z, \tau, T)$ for the same T and τ show almost the same values regardless of $S_u(z, n)$. This is believed to be due to the normalized $S_u(z, n)$ being integrated. The maxima of $g_u(z, \tau, 3600)$ are 3.8, 3.1, 2.1, and 0.9 at $\tau=0.25, 3, 60, \text{ and } 600$, respectively; those of $g_u(z, \tau, 600)$ are 3.3, 2.5, and 1.2 at $\tau=0.25, 3, \text{ and } 60$, respectively; and that of $g_u(z, \tau, 3)$ is 1.3 at $\tau=0.25$. In addition, the same spectral type has a recognizable regularity in $L_u(z)/\bar{U}(z)$ at the maximum point of $g_u(z, \tau, T)$. The ratio of $L_u(z)/\bar{U}(z)$ of Types C-2 to C-1 is 11.9 for all τ regardless of T . That is the same ratio of non-dimensional peak frequency as Types C-2 to C-1. This fact shows that the curves of $g_u(z, \tau, T)$ for Type C-2 overlap those for Type C-1 by the coordinate transformation corresponding to its ratio. The same relationship also applies to Type B.

These discussions conclude that the curves of $g_u(z, \tau, T)$ give practical results overall for all combinations. As a result, $g_u(z, \tau, T)$ enables us to convert wind speeds referenced to any height over any terrain into different conditions without any difficulties by only a $L_u(z)/\bar{U}(z)$. However, a return period needs to be considered separately.

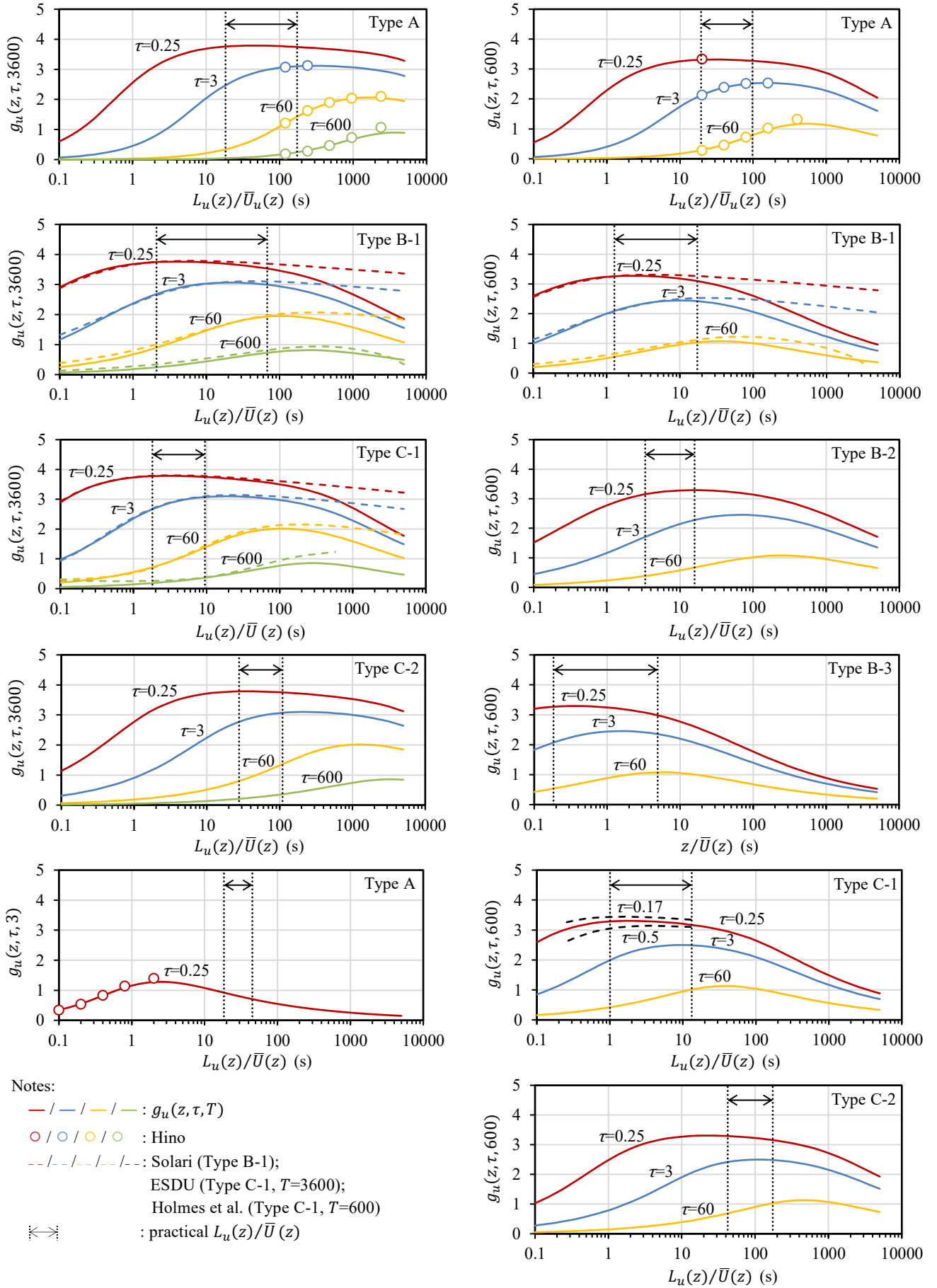


Figure 5.9 Peak factors for 11 combinations of turbulence spectra and sampling lengths

Table 5.7 Peak factors for Type A

$L_u(z)$ $\bar{U}(z)$ (s)	$T=3600$					$T=600$					$T=3$				
	$\tau(s)$					$\tau(s)$					$\tau(s)$				
	0.25	3	60	600	3600	0.25	3	60	600	3600	0.25	3	60	600	3600
0.10	0.60	0.07	0.00	0.00	0.00	0.55	0.06	0.00	0.00	-	0.34	0.00	-	-	-
0.12	0.71	0.08	0.00	0.00	0.00	0.65	0.07	0.00	0.00	-	0.40	0.00	-	-	-
0.15	0.84	0.10	0.01	0.00	0.00	0.76	0.09	0.01	0.00	-	0.46	0.00	-	-	-
0.19	0.99	0.11	0.01	0.00	0.00	0.90	0.10	0.01	0.00	-	0.53	0.00	-	-	-
0.24	1.16	0.14	0.01	0.00	0.00	1.05	0.12	0.01	0.00	-	0.61	0.00	-	-	-
0.30	1.35	0.17	0.01	0.00	0.00	1.22	0.15	0.01	0.00	-	0.70	0.00	-	-	-
0.37	1.56	0.20	0.01	0.00	0.00	1.40	0.18	0.01	0.00	-	0.78	0.00	-	-	-
0.45	1.77	0.24	0.02	0.00	0.00	1.60	0.21	0.01	0.00	-	0.87	0.00	-	-	-
0.56	2.00	0.29	0.02	0.00	0.00	1.80	0.25	0.02	0.00	-	0.96	0.00	-	-	-
0.70	2.22	0.34	0.02	0.00	0.00	1.99	0.30	0.02	0.00	-	1.04	0.00	-	-	-
0.87	2.43	0.41	0.03	0.00	0.00	2.18	0.36	0.02	0.00	-	1.11	0.00	-	-	-
1.1	2.63	0.48	0.03	0.00	0.00	2.35	0.43	0.03	0.00	-	1.17	0.00	-	-	-
1.3	2.81	0.57	0.04	0.00	0.00	2.51	0.50	0.03	0.00	-	1.22	0.00	-	-	-
1.7	2.97	0.67	0.05	0.01	0.00	2.66	0.59	0.04	0.00	-	1.25	0.00	-	-	-
2.1	3.12	0.79	0.06	0.01	0.00	2.78	0.70	0.05	0.00	-	1.27	0.00	-	-	-
2.6	3.24	0.93	0.07	0.01	0.00	2.89	0.81	0.06	0.00	-	1.28	0.00	-	-	-
3.2	3.35	1.08	0.08	0.01	0.00	2.98	0.94	0.07	0.00	-	1.27	0.00	-	-	-
4.0	3.44	1.25	0.10	0.01	0.00	3.06	1.09	0.08	0.00	-	1.25	0.00	-	-	-
4.9	3.52	1.43	0.12	0.01	0.00	3.12	1.24	0.10	0.00	-	1.22	0.00	-	-	-
6.1	3.58	1.62	0.14	0.02	0.00	3.18	1.39	0.12	0.00	-	1.18	0.00	-	-	-
7.6	3.64	1.81	0.17	0.02	0.00	3.22	1.55	0.14	0.00	-	1.14	0.00	-	-	-
9.4	3.68	1.99	0.20	0.02	0.00	3.25	1.70	0.17	0.00	-	1.09	0.00	-	-	-
11.7	3.71	2.16	0.24	0.03	0.00	3.28	1.84	0.20	0.00	-	1.04	0.00	-	-	-
14.5	3.74	2.32	0.28	0.04	0.00	3.29	1.97	0.23	0.00	-	0.98	0.00	-	-	-
18.0	3.76	2.46	0.33	0.04	0.00	3.31	2.09	0.27	0.00	-	0.93	0.00	-	-	-
22.4	3.77	2.58	0.39	0.05	0.00	3.31	2.19	0.32	0.00	-	0.87	0.00	-	-	-
27.8	3.78	2.69	0.46	0.06	0.00	3.32	2.27	0.37	0.00	-	0.82	0.00	-	-	-
34.5	3.79	2.78	0.54	0.07	0.00	3.32	2.34	0.43	0.00	-	0.77	0.00	-	-	-
42.8	3.79	2.86	0.63	0.08	0.00	3.31	2.40	0.49	0.00	-	0.72	0.00	-	-	-
53.1	3.79	2.93	0.74	0.10	0.00	3.31	2.44	0.56	0.00	-	0.67	0.00	-	-	-
66.0	3.78	2.98	0.85	0.12	0.00	3.30	2.48	0.64	0.00	-	0.62	0.00	-	-	-
81.9	3.78	3.02	0.98	0.14	0.00	3.29	2.51	0.72	0.00	-	0.58	0.00	-	-	-
101.7	3.77	3.05	1.11	0.16	0.00	3.27	2.52	0.80	0.00	-	0.54	0.00	-	-	-
126.3	3.76	3.08	1.24	0.19	0.00	3.26	2.53	0.89	0.00	-	0.51	0.00	-	-	-
156.8	3.75	3.10	1.37	0.23	0.00	3.24	2.53	0.96	0.00	-	0.47	0.00	-	-	-
194.7	3.74	3.11	1.49	0.26	0.00	3.21	2.53	1.03	0.00	-	0.44	0.00	-	-	-
241.7	3.72	3.11	1.61	0.30	0.00	3.19	2.52	1.08	0.00	-	0.41	0.00	-	-	-
300.1	3.71	3.12	1.71	0.35	0.00	3.16	2.50	1.13	0.00	-	0.38	0.00	-	-	-
372.6	3.69	3.11	1.80	0.40	0.00	3.13	2.48	1.16	0.00	-	0.35	0.00	-	-	-
462.6	3.68	3.11	1.88	0.46	0.00	3.09	2.45	1.17	0.00	-	0.33	0.00	-	-	-
574.3	3.66	3.10	1.94	0.52	0.00	3.04	2.41	1.18	0.00	-	0.31	0.00	-	-	-
713.1	3.64	3.09	1.99	0.58	0.00	2.98	2.37	1.17	0.00	-	0.28	0.00	-	-	-
885.4	3.62	3.07	2.02	0.65	0.00	2.91	2.31	1.14	0.00	-	0.27	0.00	-	-	-
1099.3	3.59	3.05	2.05	0.71	0.00	2.83	2.24	1.11	0.00	-	0.25	0.00	-	-	-
1364.9	3.57	3.03	2.06	0.76	0.00	2.74	2.17	1.08	0.00	-	0.23	0.00	-	-	-
1694.6	3.54	3.01	2.06	0.81	0.00	2.64	2.09	1.03	0.00	-	0.21	0.00	-	-	-
2104.0	3.50	2.98	2.06	0.85	0.00	2.53	2.00	0.98	0.00	-	0.20	0.00	-	-	-
2612.4	3.46	2.94	2.04	0.88	0.00	2.41	1.90	0.93	0.00	-	0.18	0.00	-	-	-
3243.5	3.41	2.90	2.02	0.89	0.00	2.29	1.80	0.88	0.00	-	0.17	0.00	-	-	-
4027.1	3.36	2.84	1.99	0.90	0.00	2.16	1.70	0.83	0.00	-	0.16	0.00	-	-	-
5000.0	3.29	2.78	1.94	0.89	0.00	2.04	1.60	0.78	0.00	-	0.15	0.00	-	-	-

Table 5.8 Peak factors for Type B-1

$L_u(z)$ $\bar{U}(z)$ (s)	$T=3600$					$T=600$				
	$\tau(s)$					$\tau(s)$				
	0.25	3	60	600	3600	0.25	3	60	600	3600
0.10	3.51	2.90	1.16	0.25	0.07	2.59	1.01	0.20	0.00	-
0.12	3.59	3.02	1.27	0.28	0.07	2.69	1.09	0.22	0.00	-
0.15	3.67	3.13	1.37	0.30	0.08	2.79	1.18	0.24	0.00	-
0.19	3.73	3.23	1.48	0.33	0.09	2.87	1.28	0.26	0.00	-
0.24	3.78	3.32	1.60	0.37	0.10	2.95	1.37	0.29	0.00	-
0.30	3.83	3.40	1.72	0.40	0.11	3.02	1.47	0.31	0.00	-
0.37	3.87	3.47	1.84	0.44	0.12	3.07	1.57	0.34	0.00	-
0.45	3.90	3.53	1.96	0.49	0.13	3.12	1.67	0.37	0.00	-
0.56	3.93	3.58	2.08	0.53	0.14	3.16	1.76	0.40	0.00	-
0.70	3.95	3.62	2.19	0.58	0.16	3.20	1.86	0.44	0.00	-
0.87	3.96	3.66	2.30	0.64	0.17	3.23	1.95	0.48	0.00	-
1.1	3.97	3.69	2.41	0.70	0.19	3.25	2.03	0.52	0.00	-
1.3	3.98	3.72	2.51	0.76	0.20	3.26	2.11	0.56	0.00	-
1.7	3.98	3.73	2.60	0.82	0.22	3.27	2.18	0.60	0.00	-
2.1	3.98	3.75	2.68	0.89	0.24	3.28	2.24	0.64	0.00	-
2.6	3.98	3.76	2.76	0.97	0.26	3.27	2.29	0.69	0.00	-
3.2	3.98	3.76	2.82	1.04	0.29	3.27	2.34	0.74	0.00	-
4.0	3.97	3.76	2.88	1.12	0.31	3.26	2.38	0.78	0.00	-
4.9	3.96	3.76	2.93	1.20	0.34	3.25	2.41	0.83	0.00	-
6.1	3.95	3.75	2.97	1.28	0.37	3.23	2.43	0.87	0.00	-
7.6	3.94	3.75	3.00	1.36	0.40	3.21	2.44	0.91	0.00	-
9.4	3.92	3.74	3.02	1.44	0.43	3.19	2.44	0.95	0.00	-
11.7	3.91	3.72	3.04	1.52	0.46	3.16	2.44	0.99	0.00	-
14.5	3.89	3.71	3.06	1.59	0.50	3.13	2.43	1.02	0.00	-
18.0	3.87	3.69	3.06	1.66	0.53	3.09	2.42	1.04	0.00	-
22.4	3.85	3.67	3.06	1.73	0.56	3.05	2.39	1.06	0.00	-
27.8	3.82	3.65	3.06	1.78	0.60	3.00	2.36	1.07	0.00	-
34.5	3.80	3.63	3.05	1.83	0.63	2.94	2.33	1.07	0.00	-
42.8	3.77	3.60	3.04	1.87	0.66	2.89	2.28	1.07	0.00	-
53.1	3.74	3.57	3.02	1.90	0.70	2.82	2.24	1.06	0.00	-
66.0	3.70	3.54	3.00	1.93	0.72	2.75	2.18	1.05	0.00	-
81.9	3.66	3.50	2.97	1.94	0.75	2.67	2.12	1.03	0.00	-
101.7	3.62	3.46	2.94	1.95	0.77	2.59	2.05	1.00	0.00	-
126.3	3.57	3.41	2.90	1.95	0.79	2.50	1.98	0.97	0.00	-
156.8	3.52	3.36	2.86	1.94	0.80	2.41	1.91	0.94	0.00	-
194.7	3.46	3.30	2.81	1.92	0.81	2.32	1.83	0.90	0.00	-
241.7	3.40	3.24	2.75	1.89	0.81	2.22	1.75	0.86	0.00	-
300.1	3.33	3.17	2.69	1.86	0.81	2.12	1.67	0.82	0.00	-
372.6	3.25	3.10	2.63	1.82	0.81	2.02	1.59	0.78	0.00	-
462.6	3.16	3.02	2.56	1.78	0.79	1.91	1.51	0.74	0.00	-
574.3	3.07	2.93	2.48	1.73	0.78	1.81	1.43	0.70	0.00	-
713.1	2.97	2.83	2.40	1.67	0.76	1.71	1.35	0.66	0.00	-
885.4	2.87	2.73	2.31	1.61	0.73	1.61	1.27	0.62	0.00	-
1099.3	2.76	2.63	2.22	1.55	0.71	1.52	1.20	0.58	0.00	-
1364.9	2.64	2.52	2.13	1.48	0.68	1.43	1.12	0.55	0.00	-
1694.6	2.53	2.41	2.03	1.41	0.65	1.34	1.05	0.51	0.00	-
2104.0	2.41	2.29	1.94	1.34	0.62	1.26	0.99	0.48	0.00	-
2612.4	2.29	2.18	1.84	1.27	0.59	1.18	0.92	0.45	0.00	-
3243.5	2.17	2.07	1.74	1.21	0.56	1.10	0.86	0.42	0.00	-
4027.1	2.06	1.96	1.65	1.14	0.53	1.03	0.81	0.39	0.00	-
5000.0	1.94	1.85	1.55	1.07	0.49	0.96	0.75	0.36	0.00	-

Table 5.9 Peak factors for Types B-2 and B-3

$L_u(z)$ $\bar{U}(z)$ (s)	Type B-2					Type B-3				
	$\tau(s)$					$\tau(s)$				
	0.25	3	60	600	3600	0.25	3	60	600	3600
0.10	1.52	0.45	0.09	0.00	-	3.20	1.83	0.43	0.00	-
0.12	1.64	0.50	0.09	0.00	-	3.23	1.92	0.46	0.00	-
0.15	1.76	0.54	0.10	0.00	-	3.25	2.01	0.50	0.00	-
0.19	1.89	0.60	0.11	0.00	-	3.27	2.09	0.54	0.00	-
0.24	2.02	0.66	0.13	0.00	-	3.28	2.16	0.59	0.00	-
0.30	2.14	0.72	0.14	0.00	-	3.29	2.23	0.63	0.00	-
0.37	2.27	0.79	0.15	0.00	-	3.29	2.28	0.67	0.00	-
0.45	2.39	0.86	0.17	0.00	-	3.29	2.33	0.72	0.00	-
0.56	2.51	0.94	0.18	0.00	-	3.28	2.37	0.77	0.00	-
0.70	2.62	1.02	0.20	0.00	-	3.27	2.41	0.81	0.00	-
0.87	2.72	1.11	0.22	0.00	-	3.26	2.43	0.86	0.00	-
1.1	2.81	1.20	0.24	0.00	-	3.24	2.45	0.90	0.00	-
1.3	2.89	1.29	0.26	0.00	-	3.21	2.45	0.94	0.00	-
1.7	2.97	1.39	0.29	0.00	-	3.19	2.46	0.98	0.00	-
2.1	3.04	1.49	0.32	0.00	-	3.15	2.45	1.01	0.00	-
2.6	3.09	1.59	0.35	0.00	-	3.12	2.44	1.04	0.00	-
3.2	3.14	1.69	0.38	0.00	-	3.08	2.42	1.06	0.00	-
4.0	3.18	1.78	0.41	0.00	-	3.03	2.39	1.07	0.00	-
4.9	3.22	1.88	0.45	0.00	-	2.98	2.35	1.08	0.00	-
6.1	3.24	1.97	0.48	0.00	-	2.93	2.31	1.08	0.00	-
7.6	3.26	2.05	0.52	0.00	-	2.86	2.27	1.07	0.00	-
9.4	3.28	2.13	0.56	0.00	-	2.79	2.22	1.06	0.00	-
11.7	3.29	2.19	0.61	0.00	-	2.72	2.16	1.04	0.00	-
14.5	3.29	2.26	0.65	0.00	-	2.64	2.09	1.02	0.00	-
18.0	3.29	2.31	0.70	0.00	-	2.55	2.02	0.99	0.00	-
22.4	3.29	2.35	0.74	0.00	-	2.46	1.95	0.96	0.00	-
27.8	3.28	2.39	0.79	0.00	-	2.37	1.88	0.92	0.00	-
34.5	3.26	2.42	0.84	0.00	-	2.27	1.80	0.88	0.00	-
42.8	3.25	2.44	0.88	0.00	-	2.17	1.72	0.84	0.00	-
53.1	3.22	2.45	0.92	0.00	-	2.07	1.63	0.80	0.00	-
66.0	3.20	2.46	0.96	0.00	-	1.97	1.55	0.76	0.00	-
81.9	3.17	2.45	0.99	0.00	-	1.86	1.47	0.72	0.00	-
101.7	3.14	2.44	1.02	0.00	-	1.76	1.39	0.68	0.00	-
126.3	3.10	2.43	1.05	0.00	-	1.66	1.31	0.64	0.00	-
156.8	3.06	2.40	1.07	0.00	-	1.57	1.23	0.60	0.00	-
194.7	3.01	2.37	1.08	0.00	-	1.47	1.16	0.56	0.00	-
241.7	2.95	2.33	1.08	0.00	-	1.38	1.09	0.53	0.00	-
300.1	2.89	2.29	1.08	0.00	-	1.30	1.02	0.49	0.00	-
372.6	2.83	2.24	1.07	0.00	-	1.22	0.96	0.46	0.00	-
462.6	2.76	2.19	1.05	0.00	-	1.14	0.89	0.43	0.00	-
574.3	2.68	2.12	1.03	0.00	-	1.06	0.84	0.40	0.00	-
713.1	2.60	2.06	1.00	0.00	-	0.99	0.78	0.38	0.00	-
885.4	2.51	1.99	0.97	0.00	-	0.93	0.73	0.35	0.00	-
1099.3	2.41	1.91	0.94	0.00	-	0.86	0.68	0.33	0.00	-
1364.9	2.32	1.84	0.90	0.00	-	0.81	0.63	0.30	0.00	-
1694.6	2.22	1.76	0.86	0.00	-	0.75	0.59	0.28	0.00	-
2104.0	2.12	1.67	0.82	0.00	-	0.70	0.55	0.26	0.00	-
2612.4	2.02	1.59	0.78	0.00	-	0.65	0.51	0.25	0.00	-
3243.5	1.91	1.51	0.74	0.00	-	0.61	0.48	0.23	0.00	-
4027.1	1.81	1.43	0.70	0.00	-	0.57	0.44	0.21	0.00	-
5000.0	1.71	1.35	0.66	0.00	-	0.53	0.41	0.20	0.00	-

Table 5.10 Peak factors for Type C-1

$L_u(z)$ $\bar{U}(z)$ (s)	$T=3600$					$T=600$				
	$\tau(s)$					$\tau(s)$				
	0.25	3	60	600	3600	0.25	3	60	600	3600
0.10	3.58	2.90	0.98	0.20	0.05	2.59	0.85	0.16	0.00	-
0.12	3.66	3.04	1.08	0.22	0.06	2.71	0.93	0.17	0.00	-
0.15	3.74	3.17	1.19	0.24	0.06	2.82	1.03	0.19	0.00	-
0.19	3.80	3.28	1.30	0.27	0.07	2.92	1.12	0.21	0.00	-
0.24	3.85	3.38	1.43	0.29	0.08	3.00	1.23	0.23	0.00	-
0.30	3.89	3.46	1.56	0.32	0.09	3.07	1.34	0.25	0.00	-
0.37	3.93	3.54	1.70	0.36	0.09	3.13	1.45	0.28	0.00	-
0.45	3.95	3.59	1.84	0.39	0.10	3.18	1.57	0.30	0.00	-
0.56	3.97	3.64	1.98	0.43	0.11	3.22	1.69	0.33	0.00	-
0.70	3.99	3.68	2.13	0.48	0.12	3.25	1.81	0.36	0.00	-
0.87	4.00	3.72	2.27	0.52	0.14	3.27	1.92	0.40	0.00	-
1.1	4.01	3.74	2.40	0.58	0.15	3.29	2.03	0.44	0.00	-
1.3	4.01	3.76	2.52	0.63	0.16	3.30	2.13	0.47	0.00	-
1.7	4.01	3.77	2.63	0.69	0.18	3.31	2.21	0.52	0.00	-
2.1	4.00	3.78	2.72	0.76	0.20	3.31	2.28	0.56	0.00	-
2.6	4.00	3.78	2.81	0.83	0.22	3.30	2.35	0.61	0.00	-
3.2	3.99	3.79	2.88	0.91	0.24	3.30	2.40	0.66	0.00	-
4.0	3.98	3.78	2.94	1.00	0.26	3.29	2.44	0.71	0.00	-
4.9	3.97	3.78	2.98	1.08	0.28	3.27	2.46	0.77	0.00	-
6.1	3.96	3.77	3.02	1.18	0.31	3.26	2.48	0.82	0.00	-
7.6	3.95	3.76	3.05	1.27	0.33	3.24	2.50	0.88	0.00	-
9.4	3.93	3.75	3.07	1.37	0.36	3.21	2.50	0.93	0.00	-
11.7	3.92	3.74	3.09	1.47	0.40	3.19	2.50	0.98	0.00	-
14.5	3.90	3.72	3.10	1.57	0.43	3.16	2.48	1.03	0.00	-
18.0	3.88	3.71	3.10	1.66	0.46	3.12	2.47	1.07	0.00	-
22.4	3.86	3.69	3.10	1.74	0.50	3.09	2.44	1.10	0.00	-
27.8	3.84	3.67	3.09	1.81	0.54	3.04	2.41	1.12	0.00	-
34.5	3.81	3.64	3.08	1.87	0.58	3.00	2.38	1.13	0.00	-
42.8	3.79	3.62	3.07	1.92	0.62	2.94	2.34	1.13	0.00	-
53.1	3.76	3.59	3.05	1.96	0.66	2.88	2.29	1.12	0.00	-
66.0	3.73	3.57	3.03	1.99	0.70	2.81	2.23	1.10	0.00	-
81.9	3.70	3.53	3.00	2.01	0.74	2.73	2.16	1.07	0.00	-
101.7	3.66	3.50	2.97	2.02	0.77	2.64	2.09	1.04	0.00	-
126.3	3.62	3.46	2.94	2.01	0.80	2.55	2.02	1.00	0.00	-
156.8	3.58	3.41	2.90	2.00	0.83	2.44	1.93	0.95	0.00	-
194.7	3.53	3.36	2.86	1.98	0.85	2.34	1.84	0.91	0.00	-
241.7	3.47	3.31	2.80	1.95	0.86	2.22	1.75	0.86	0.00	-
300.1	3.40	3.24	2.75	1.92	0.86	2.11	1.66	0.81	0.00	-
372.6	3.32	3.17	2.68	1.87	0.85	1.99	1.57	0.76	0.00	-
462.6	3.24	3.08	2.61	1.82	0.84	1.87	1.48	0.72	0.00	-
574.3	3.14	2.99	2.53	1.76	0.82	1.76	1.39	0.67	0.00	-
713.1	3.03	2.89	2.44	1.70	0.79	1.65	1.30	0.63	0.00	-
885.4	2.92	2.78	2.34	1.63	0.76	1.55	1.22	0.59	0.00	-
1099.3	2.79	2.66	2.24	1.56	0.72	1.45	1.14	0.55	0.00	-
1364.9	2.66	2.53	2.13	1.48	0.69	1.35	1.06	0.51	0.00	-
1694.6	2.53	2.40	2.02	1.40	0.65	1.26	0.99	0.48	0.00	-
2104.0	2.39	2.27	1.91	1.32	0.61	1.18	0.92	0.44	0.00	-
2612.4	2.25	2.14	1.80	1.24	0.57	1.10	0.86	0.41	0.00	-
3243.5	2.12	2.02	1.70	1.17	0.54	1.02	0.80	0.39	0.00	-
4027.1	1.99	1.89	1.59	1.10	0.50	0.95	0.75	0.36	0.00	-
5000.0	1.86	1.77	1.49	1.03	0.47	0.89	0.69	0.33	0.00	-

Table 5.11 Peak factors for Type C-2

$L_u(z)$ $\bar{U}(z)$ (s)	$T=3600$					$T=600$				
	$\tau(s)$					$\tau(s)$				
	0.25	3	60	600	3600	0.25	3	60	600	3600
0.10	1.14	0.31	0.06	0.02	0.00	1.03	0.28	0.05	0.00	-
0.12	1.25	0.34	0.07	0.02	0.00	1.13	0.31	0.06	0.00	-
0.15	1.38	0.38	0.08	0.02	0.00	1.25	0.34	0.06	0.00	-
0.19	1.52	0.42	0.09	0.02	0.00	1.37	0.37	0.07	0.00	-
0.24	1.67	0.47	0.09	0.03	0.00	1.50	0.41	0.08	0.00	-
0.30	1.82	0.52	0.10	0.03	0.00	1.64	0.46	0.09	0.00	-
0.37	1.99	0.57	0.12	0.03	0.00	1.79	0.50	0.09	0.00	-
0.45	2.16	0.63	0.13	0.03	0.00	1.94	0.55	0.10	0.00	-
0.56	2.33	0.70	0.14	0.04	0.00	2.09	0.61	0.11	0.00	-
0.70	2.51	0.77	0.16	0.04	0.00	2.25	0.67	0.13	0.00	-
0.87	2.67	0.85	0.17	0.05	0.00	2.39	0.74	0.14	0.00	-
1.1	2.83	0.94	0.19	0.05	0.00	2.53	0.82	0.15	0.00	-
1.3	2.98	1.03	0.21	0.06	0.00	2.66	0.90	0.17	0.00	-
1.7	3.11	1.14	0.23	0.06	0.00	2.78	0.98	0.18	0.00	-
2.1	3.23	1.25	0.25	0.07	0.00	2.88	1.08	0.20	0.00	-
2.6	3.34	1.37	0.28	0.07	0.00	2.97	1.18	0.22	0.00	-
3.2	3.43	1.50	0.31	0.08	0.00	3.05	1.29	0.24	0.00	-
4.0	3.51	1.63	0.34	0.09	0.00	3.11	1.40	0.27	0.00	-
4.9	3.57	1.78	0.38	0.10	0.00	3.16	1.52	0.29	0.00	-
6.1	3.62	1.92	0.41	0.11	0.00	3.21	1.64	0.32	0.00	-
7.6	3.67	2.06	0.46	0.12	0.00	3.24	1.76	0.35	0.00	-
9.4	3.70	2.21	0.50	0.13	0.00	3.27	1.87	0.38	0.00	-
11.7	3.73	2.34	0.55	0.14	0.00	3.28	1.98	0.42	0.00	-
14.5	3.75	2.47	0.61	0.16	0.00	3.30	2.08	0.46	0.00	-
18.0	3.77	2.58	0.67	0.17	0.00	3.30	2.17	0.50	0.00	-
22.4	3.78	2.68	0.73	0.19	0.00	3.31	2.25	0.54	0.00	-
27.8	3.78	2.77	0.80	0.21	0.00	3.31	2.32	0.59	0.00	-
34.5	3.79	2.85	0.88	0.23	0.00	3.30	2.38	0.64	0.00	-
42.8	3.79	2.91	0.96	0.25	0.00	3.29	2.42	0.69	0.00	-
53.1	3.78	2.96	1.04	0.27	0.00	3.28	2.45	0.74	0.00	-
66.0	3.78	3.01	1.14	0.30	0.00	3.26	2.48	0.80	0.00	-
81.9	3.77	3.04	1.23	0.32	0.00	3.25	2.49	0.85	0.00	-
101.7	3.76	3.07	1.33	0.35	0.00	3.22	2.50	0.91	0.00	-
126.3	3.74	3.08	1.43	0.38	0.00	3.20	2.50	0.96	0.00	-
156.8	3.73	3.09	1.53	0.41	0.00	3.17	2.49	1.01	0.00	-
194.7	3.71	3.10	1.62	0.45	0.00	3.14	2.48	1.05	0.00	-
241.7	3.70	3.10	1.70	0.48	0.00	3.10	2.46	1.09	0.00	-
300.1	3.68	3.10	1.78	0.52	0.00	3.06	2.43	1.11	0.00	-
372.6	3.65	3.09	1.85	0.56	0.00	3.02	2.40	1.13	0.00	-
462.6	3.63	3.08	1.90	0.60	0.00	2.97	2.36	1.13	0.00	-
574.3	3.61	3.06	1.95	0.64	0.00	2.91	2.31	1.12	0.00	-
713.1	3.58	3.04	1.98	0.68	0.00	2.84	2.26	1.11	0.00	-
885.4	3.55	3.01	2.00	0.72	0.00	2.77	2.19	1.09	0.00	-
1099.3	3.51	2.99	2.01	0.76	0.00	2.68	2.13	1.05	0.00	-
1364.9	3.48	2.95	2.02	0.79	0.00	2.59	2.05	1.02	0.00	-
1694.6	3.43	2.92	2.01	0.82	0.00	2.49	1.97	0.97	0.00	-
2104.0	3.39	2.88	1.99	0.84	0.00	2.38	1.88	0.93	0.00	-
2612.4	3.33	2.83	1.97	0.85	0.00	2.27	1.79	0.88	0.00	-
3243.5	3.27	2.77	1.94	0.86	0.00	2.16	1.70	0.83	0.00	-
4027.1	3.20	2.71	1.89	0.86	0.00	2.04	1.61	0.79	0.00	-
5000.0	3.12	2.64	1.85	0.85	0.00	1.93	1.52	0.74	0.00	-

Table 5.12 Maximum and minimum of $L_u(z)/\bar{U}(z)$ from 10 m to 200 m above ground

$T(s)$	Type	$L_u(z)/\bar{U}(z)(s)$	
		min.	max.
3600	A	18.4	173.1
	B-1	2.1	67.8
	C-1	1.8	9.5
	C-2	27.7	109.5
600	A	19.4	97.9
	B-1	1.3	17.3
	B-2	3.3	15.8
	B-3	0.2	4.9
	C-1	1.0	13.2
	C-2	42.4	173.9
3	A	18.4	45.1

Table 5.13 Maximum peak factors

$T(s)$	Type	$\tau(s)$			
		0.25	3	60	600
3600	A	3.8 [44]	3.1 [297]	2.1 [1,667]	0.9 [3,921]
	B-1	3.8 [3.9]	3.1 [21]	2.0 [108]	0.8 [252]
	C-1	3.8 [3.0]	3.1 [19]	2.0 [107]	0.9 [283]
	C-2	3.8 [36]	3.1 [220]	2.0 [1,275]	0.9 [3,373]
600	A	3.3 [30]	2.5 [153]	1.2 [536]	-
	B-1	3.3 [2.3]	2.5 [10]	1.1 [36]	-
	B-2	3.3 [16]	2.5 [68]	1.1 [245]	-
	B-3	3.3 [0.35]	2.5 [1.5]	1.1 [5.6]	-
	C-1	3.3 [1.9]	2.5 [9.3]	1.1 [38]	-
	C-2	3.3 [23]	2.5 [111]	1.1 [454]	-
3	A	1.3 [2.5]	-	-	-

Note: the numerical value in parentheses [] shows $L_u(z)/\bar{U}_u(z)$ at the maximum of $g_u(z, \tau, T)$ but $z/\bar{U}_u(z)$ for only Type B-3.

5.4 Wind Speed Conversion Factors

Because the specifications of reference wind speeds differ from country to country as shown in Section 5.2, comparisons through design wind speeds should also be considered. In this chapter, we apply the computed curves of $g_u(z, \tau, T)$ to the 37 representative groups, which were shown in Table 5.5, to obtain wind speed conversion factors $G_u(z, \tau, T)$ and compare them to those obtained in previous studies. Then, we discuss practical considerations in conversions and comparisons of U_{ref} in national border areas from three perspectives: 1) statistically analytical approaches, 2) turbulence spectra and scales, and 3) height and terrain situations.

5.4.1 Practical application examples

$G_u(z, \tau, T)$ is calculated at $z=10$ or 200 over level ground with few or some obstructions. Here, level ground with few obstructions roughly represents the countryside, and level ground with some obstructions roughly represents the outskirts. Table 5.14 and Table 5.15 summarize roughness length z_0 (m) and $K_u(z)$ scaling exponent ε , as well as $L_u(z)$, $\bar{U}(z)$, $L_u(z)/\bar{U}(z)$, and $I_u(z)$ for 37 representative groups. For BS EN NA'10, z is 10 m or 200 m above the sea. RSAEEP'08 neither defines level ground with few obstructions nor level ground with some obstructions. FLK'95&DS 410'82 does not define level ground with few obstructions. Roughness heights of $I_u(z)$ and $L_u(z)$ are taken to follow those of $K_u(z)$ if they are not separately defined.

(1) z_0 and ε

Over level ground with few obstructions, z_0 is 0.02, 0.05, or 0.3 and ε is 0.14 or 0.15 for $T=3600$; z_0 is 0.05, 0.07, or 0.2 and ε is 0.15, 0.16, or 0.19 for $T=600$; and ε is 0.09 for $T=3$. Of these, NEN 6702'07 and NEN EN NA'11 define z_0 as 0.1, 0.2, or 0.3 (Table 5.14 shows one of these values.) and 0.2, respectively, which are larger than any other representative group. Over level ground with some obstructions, z_0 is 0.2, 0.3, or 0.7 and ε is 0.22 or 0.25 for $T=3600$; z_0 is 0.1, 0.2, 0.3, or 0.5 and ε is 0.185, 0.2, 0.21, 0.22, or 0.23 for $T=600$; and ε is 0.14 for $T=3$. In common with the former case, NEN 6702'07 and NEN EN NA'11 define z_0 to be slightly larger than those of any other representative group. BS EN NA'10 assumes that typical farmlands located 20 km and 100 km from the sea represent level ground with few and some obstructions, respectively.

(2) $\bar{U}(z)$, $L_u(z)$ and $L_u(z)/\bar{U}(z)$

1) $\bar{U}(z)$

$\bar{U}(z)$ is calculated from U_{ref} , which is converted into a 50-year return period as necessary, and $K_u(z)$. In this regard, the minimum and maximum of $\bar{U}(z)$ are determined from all 113 codes and standards belonging to each representative group. Specifically, for ASCE 7'98/'02/'05/'10/'16, the minimum and maximum $\bar{U}(z)$ are determined from NB 1225003'14 and NBCBD'20, respectively. For EN'05, the minimum and maximum $\bar{U}(z)$ are determined from MKC EN NA'20 and GL EN NA'10, respectively. For NEN 6702'07, the country and territory that adopt it do not define $\bar{U}(z)$ with the same T as it. As a result,

over level ground with few obstructions, $\bar{U}(10)$ lies within the range from 2.9 to 61 for $T=3600$, from 14 to 54 for $T=600$, and from 33 to 60 for $T=3$. $\bar{U}(200)$ lies within the range from 4.6 to 96 for $T=3600$, from 22 to 85 for $T=600$, and from 43 to 79 for $T=3$. Over level ground with some obstructions, $\bar{U}(10)$ lies within the range from 2.0 to 40 for $T=3600$, from 11 to 44 for $T=600$, and from 27 to 49 for $T=3$. For ECP-201'12, $\bar{U}(10)$ over level ground with some obstructions has the same value as that over level ground with few obstructions, unlike any other representative group. This is due to the definition of roughness heights of $K_u(z)$.

2) $L_u(z)$

$L_u(10)$ is clearly divided into two groups: 1,000 or more like Types A and C-2 and 200 or less like Types B-1, B-2, B-3, and C-1, regardless of terrain roughness. $L_u(200)$ is also similarly divided into two groups: 1,220 or more for Types A and C-2 and 300 or less for Types B-1, B-2, B-3, and C-1. Of these, however, NBCCA'05/'10/'15, ANSI A58.1'82/ASCE 7'88, NEN 6702'07, GB 50009'12, SNiP 2.01.07'88/'05/SP 20.13330'16, SP 201.1325800'14, NBR 6123'13, and TCVN 2737'96 show scales calculated from characteristic scales and $K_u(z)$ as $L_u(10)$ and $L_u(200)$. Additionally, SIA 261'14/SN EN NA'16 shows z ($=10$ or 200) instead of $L_u(10)$ and $L_u(200)$. For ECP-201'12 and KDS 41 10 15'19, $L_u(10)$ over level ground with some obstructions is larger than that over level ground with few obstructions, unlike any other representative group. This is also due to the definition of roughness heights of $L_u(z)$, which follows that of $K_u(z)$.

3) $L_u(z)/\bar{U}(z)$

Other than ASCE 7'98/'02/'05/'10/'16 with Type B-1, $L_u(10)/\bar{U}(10)$ is roughly divided into two groups: 22 or more for Types A and C-2 and 9.5 or less for Types B-1, B-2, B-3, and C-1, regardless of terrain roughness. $L_u(200)/\bar{U}(200)$ is also similarly divided into two groups: 18 or more for Types A and C-2 and 14 or less for Types B-1, B-2, B-3, and C-1. Only ASCE 7'98/'02/'05/'10/'16 covers both the above ranges. However, $L_u(10)/\bar{U}(10)$ and $L_u(200)/\bar{U}(200)$ respectively fall within the above ranges of Type B-1, which are from 3.1 to 6.0 and from 3.9 to 6.9, using $\bar{U}(10)$ and $\bar{U}(200)$ defined in the United States. ANSI A58.1'82/ASCE 7'88, GB 50009'12, SNiP 2.01.07'88/'05/SP 20.13330'16, SP 201.1325800'14, NBR 6123'13, and TCVN 2737'96, which define the characteristic scales at 10 m above ground, show $L_u(10)/\bar{U}(10)$ regardless of height, as does PNG 1001.3'82.

(3) $I_u(z)$

Over level ground with few obstructions, $I_u(10)$ falls within the ranges from 0.16 to 0.29 for $T=3600$ and from 0.13 to 0.26 for $T=600$ and is at 0.17 for $T=3$. $I_u(200)$ falls within the ranges from 0.11 to 0.15 for $T=3600$ and from 0.08 to 0.14 for $T=600$ and is at 0.13 for $T=3$. Over level ground with some obstructions, $I_u(10)$ falls within the ranges from 0.22 to 0.40 for $T=3600$ and from 0.18 to 0.33 for $T=600$ and is at 0.25 for $T=3$. Of these, SIA 261'14/SN EN NA'16 and NBR 6123'13 show estimated values based on SIA D 0188'06 and the reference book (Blessmann 1995), respectively. $I_u(z)$ shows similar values to each other in the same terrain roughness and height AGL except in some cases where those of six representative groups: NEN 6702'07, GB 50009'12, SNiP 2.01.07'88/'05/SP 20.13330'16, SP

201.1325800'14, NEN EN NA'11, and SIA 261'14/SN EN NA'16 are slightly lower or larger than any other representative group.

Table 5.14 Specifications of practical examples at 10 m and 200 m above level ground with few obstructions

$T(s)$	Type	Representative group	$z_0(m)/\varepsilon$	$\bar{U}(10)$ (m/s)	$L_u(10)$ (m)	$\frac{L_u(10)}{\bar{U}(10)}$ (s)	$I_u(10)$	$\bar{U}(200)$ (m/s)	$L_u(200)$ (m)	$\frac{L_u(200)}{\bar{U}(200)}$ (s)	$I_u(200)$
3600	A	NBCCA'05/'10/'15	-0.14	22-44	1,220	28-57	0.16	33-66	1,220	18-37	0.11
		ANSI A58.1'82/ ASCE 7'88	-0.14	16-45	1,219	27-78	0.16	24-69	1,870	27-78	0.11
		NEN 6702'07	0.3/-	-	1,200	-	0.29	-	1,981	-	0.15
		PNGS 1001.3'82	-0.15	15-37	1,200	32-80	0.17	23-59	1,881	32-80	0.11
	B-1	ECP-201'12	0.05/-	20-28	63	2.3-3.2	0.19	32-44	300	6.7-9.4	0.12
		ASCE 7'98/'02/'05/ '10/'16	0.02/0.15	2.9-52	152	2.9-53	0.20	4.6-82	277	3.4-61	0.12
		LDVE'23	-0.15	18-25	152	6.0-8.4	0.20	29-40	277	6.9-9.7	0.12
		SCBWRD'14	-0.15	21-61	152	2.5-7.2	0.20	33-96	277	2.9-8.3	0.12
		TCVN 2737'20	-0.15	21-36	138	3.8-6.4	0.22	34-57	251	4.4-7.4	0.13
	C-1	RSAAEP'08	-	-	-	-	-	-	-	-	-
		IS 875.3'15/NBCIN'16	0.02/-	22-37	85	2.3-3.8	0.18	33-55	180	3.3-5.5	0.10
600	A	AS/NZS 1170.2'02/'11	0.02/-	19-39	85	2.2-4.4	0.18	30-61	180	2.9-6.0	0.11
		AS 1170.2'89	0.02/-	20-31	1,000	33-51	0.18	30-47	2,115	45-70	0.11
	B-1	GB 50009'12	-0.15	22-54	1,200	22-55	0.14	34-85	1,881	22-55	0.09
		SNiP 2.01.07'88/'05/ SP 20.13330'16	-0.15	19-49	1,200	24-62	0.13	30-77	1,878	24-62	0.08
		SP 201.1325800'14	0.05/0.15	20-44	1,200	27-61	0.13	31-68	1,881	27-61	0.08
		NTCV'17	0.05/0.16	18-25	63	2.6-3.6	0.19	28-40	300	7.6-11	0.12
		EN'05	0.05/-	14-49	63	1.3-4.5	0.19	22-77	300	3.9-14	0.12
		ENV'95	0.05/-	21	124	5.9	0.19	33	270	8.2	0.12
		PN EN NA'10	0.05/-	22-26	63	2.4-2.9	0.19	37-43	300	6.9-8.2	0.12
		SFS EN NA'10&'16	0.05/-	21	63	3.0	0.19	33	300	9.1	0.12
		NS EN NA'09	0.05/-	22-33	63	1.9-2.9	0.19	35-52	300	5.8-8.7	0.12
		BS EN NA'10	0.05 ^a /-	22-31 ^a	63 ^a	2.0-2.9 ^a	0.17 ^a	34-49 ^a	300	6.1-8.8 ^a	0.10 ^a
		UNI EN NA'13	0.05/-	25-31	63	2.0-2.5	0.19	39-49	300	6.1-7.6	0.12
		NP EN NA'10	0.05/-	27-30	63	2.1-2.3	0.19	43-47	300	6.3-7.1	0.12
		ONORM EN NA'13	0.05/0.15	18-28	63	2.2-3.6	0.18	28-44	300	6.8-11	0.11
		NBN EN NA'10	0.05/-	23-26	63	2.4-2.7	0.19	36-41	300	7.3-8.3	0.12
	B-2	NF EN NA'08&'12	0.05/-	17-36	63	1.7-3.7	0.19	27-57	300	5.3-11	0.12
		DIN EN NA'10	0.05/0.16	23-30	124	4.1-5.5	0.19	36-48	270	5.6-7.4	0.12
		NEN EN NA'11	0.2/-	20-24	51	2.1-2.6	0.26	35-43	300	7.0-8.5	0.14
		FLK'95&DS 410'82	-	-	-	-	-	-	-	-	-
	B-3	SIA 261'14/ SN EN NA'16	-0.19	25-47	10 ^b	0.2-0.4	0.25 ^a	43-83	200 ^b	2.4-4.6	0.14 ^a
	C-1	AIJ-RLB'15	-0.15	24-47	58	1.2-2.4	0.20	37-73	258	3.6-7.0	0.11
		KDS 41 10 15'19	-0.15	24-43	58	1.4-2.4	0.20	37-67	258	3.8-6.9	0.11
	C-2	EKS 11'19	0.05/-	21-26	150	5.7-7.1	0.19	33-41	150	3.7-4.5	0.12
		NBR 6123'13	0.07/0.15	21-35	1,800	52-87	0.21 ^a	32-54	2,821	52-87	0.13 ^a
3	A	TCVN 2737'96	-0.09	33-60	1,200	20-37	0.17	43-79	1,571	20-37	0.13

Note: the superscripts: a and b denote the value estimated and z, respectively.

Table 5.15 Specifications of practical examples at 10 m above level ground with some obstructions

$T(s)$	Type	Representative group	$z_0(m)/\varepsilon$	$\bar{U}(10)$ (m/s)	$L_u(10)$ (m)	$\frac{L_u(10)}{\bar{U}(10)}$ (s)	$I_u(10)$
3600	A	NBCCA'05/'10/'15	-0.25	15-31	1,220	40-80	0.25
		ANSI A58.1'82/ ASCE 7'88	-0.22	11-32	1,219	38-108	0.23
		NEN 6702'07	0.7/-	-	1,200	-	0.40
		PNGS 1001.3'82	-0.25	10-25	1,200	48-121	0.25
	B-1	ECP-201'12	0.3/-	20-28	94	3.4-4.7	0.22
		ASCE 7'98/'02/'05/ '10/'16	0.2/0.25	2.0-36	98	2.7-49	0.30
		LDVE'23	-0.25	13-18	98	3.9-5.4	0.30
		SCBWRD'14	-0.25	14-40	98	2.4-7.0	0.30
		TCVN 2737'20	-0.25	14-24	82	3.5-5.8	0.33
	C-1	RSAREP'08	-	-	-	-	-
		IS 875.3'15/NBCIN'16 AS/NZS 1170.2'02/'11	0.2/- 0.2/-	16-27 14-29	85 85	3.1-5.2 2.9-6.0	0.23 0.24
	C-2	AS 1170.2'89	0.2/-	14-22	1,000	45-70	0.24
600	A	GB 50009'12	-0.22	18-44	1,200	27-68	0.23
		SNiP 2.01.07'88/'05/ SP 20.13330'16	-0.2	16-40	1,200	30-77	0.18
		SP 201.1325800'14	0.3/0.2	16-35	1,200	34-76	0.18
		NTCV'17	0.3/0.21	14-19	48	2.6-3.6	0.29
	B-1	EN'05	0.3/-	11-37	48	1.3-4.6	0.29
		ENV'95	0.3/-	16	85	5.3	0.29
		PN EN NA'10	0.3/-	18-21	48	2.3-2.7	0.29
		SFS EN NA'10&'16	0.3/-	16	48	3.0	0.29
		NS EN NA'09	0.3/-	17-25	48	1.9-2.9	0.29
		BS EN NA'10	0.3 ^a /-	16-23 ^a	48 ^a	2.1-3.0 ^a	0.27 ^a
		UNI EN NA'13	0.1/-	23-29	57	2.0-2.5	0.22
		NP EN NA'10	0.3/-	20-23	48	2.1-2.4	0.29
		ONORM EN NA'13	0.3/0.21	14-22	48	2.2-3.6	0.29
		NBN EN NA'10	0.3/-	17-20	48	2.5-2.8	0.27
		NF EN NA'08&'12	0.2/-	14-29	51	1.7-3.7	0.25
		DIN EN NA'10	0.3/0.22	17-23	85	3.7-4.9	0.28
		NEN EN NA'11	0.5/-	16-20	45	2.3-2.7	0.33
	B-2	FLK'95&DS 410'82	0.2/-	30-42	200	4.8-6.8	0.29
	B-3	SIA 261'14/ SN EN NA'16	0.3/0.23	20-39	10 ^b	0.3-0.5	0.30 ^a
	C-1	AIJ-RLB'15	-0.2	19-37	58	1.6-3.1	0.26
		KDS 41 10 15'19	-0.22	19-35	71	2.0-3.6	0.25
		EKS 11'19	0.3/-	16-20	150	7.6-9.5	0.29
	C-2	NBR 6123'13	0.3/0.185	18-30	1,800	61-101	0.29 ^a
3	A	TCVN 2737'96	-0.14	27-49	1,200	25-45	0.25

Note: the superscripts: a and b denote the value estimated and z, respectively.

5.4.2 Practical considerations

Figure 5.10 shows curves of $G_u(z, \tau, T)$ from $\tau=0.1$ to 3600 for 11 representative groups, and furthermore Table 5.16 to Table 5.18 list their numerical data. The breakdown of these groups is as follows: four groups with $T=3600$: NBCCA'05/'10/'15, ASCE '98/'02/'05/'10/'16, AS/NZS 1170.2'02/'11, and AS 1170.2'89, which adopt Types A, B-1, C-1, and C-2, respectively; six groups with $T=600$: GB 50009'12, EN'05, FLK'95&DS 410'82, SIA 261'14/SN EN NA'16, AIJ-RLB'15, and NBR 6123'13, which adopt Types A, B-1, B-2, B-3, C-1, and C-2, respectively; and one group with $T=3$: TCVN 2737'96. Two solid lines, colored red and blue, represent $G_u(z, \tau, T)$ for the maximum and minimum $L_u(z)/\bar{U}(z)$, respectively. Of these, f10 and f200 show $G_u(10, \tau, T)$ and $G_u(200, \tau, T)$ over level ground with few obstructions, respectively, and s10 shows $G_u(10, \tau, T)$ over level ground with some obstructions. FLK'95&DS 410'82 shows only s10. The circles show the Durst factors (Durst 1960) for $T=3600$ and the Miller factors (Miller 2011) for $T=600$. The Durst factors were calculated using strong wind records over unobstructed flat fields, where $\hat{u}(z, \tau, T)/\sigma_u(z, \tau, T)$ is the reduced variate value of a standard normal distribution for a cumulative probability equal to $1 - \tau/T$. The Miller factors were calculated using an expanded data set from the same data source used by Durst, where $\hat{u}(z, \tau, T)/\sigma_u(z, \tau, T)$ is the expected maximum variate value from order statistics with a sample size T/τ given a standard normal distribution as a parent distribution.

According to this figure, although $I_u(z)$ greatly affects $G_u(z, \tau, T)$, it was confirmed that except in isolated cases:

- $G_u(z, \tau, T)$ exhibits characteristic S-shaped forms with a monotonic decrease as τ increases,
- $G_u(z, \tau, T)$ becomes approximately equal at maximum and minimum $L_u(z)/\bar{U}(z)$ as τ decreases, and
- $G_u(z, \tau, T)$ is larger for maximum $L_u(z)/\bar{U}(z)$ than for minimum $L_u(z)/\bar{U}(z)$ at high τ . The magnitude of this relationship is reversed as τ decreases.

(1) Statistically analytical approaches

The Durst curve has been widely referenced in many codes and standards such as the series of ASCE standards. Therefore, it is very meaningful to discuss $G_u(z, \tau, 3600)$ in comparison with the Durst factors, which were the basis of the Durst curve. Figure 5.10 shows that f10 decreases more sharply with an increase in τ than the Durst factors for $T=3600$, regardless of $S_u(z, n)$. Therefore, ASCE 7'98/'02/'05/'10/'16, AS/NZS 1170.2'02/'11, and AS 1170.2'89 show larger factors at $\tau=0.25$ than the Durst factors, but the magnitude relationship is reversed beyond $\tau=5$. However, NBCCA'05/'10/'15 is lower at each τ than the Durst factors. The similar trends not only apply to f10 for $T=600$ but also explain f10 for $T=3$. However, EN'05 and AIJ-RLB'15 show trends relatively close to the Miller factors. GB 50009'12, whose $I_u(10)$ is the second lowest ($=0.14$) for $T=600$, drops below the Miller factors, and NBR 6123'13, whose $I_u(10)$ is the third highest ($=0.21$) for $T=600$, rises above the Miller factors, at any τ . SIA 261'14/SN EN NA'16, whose $I_u(10)$ is the second highest ($=0.25$) for $T=600$, substantially deviates from the Miller factors as τ decreases.

As discussed above, $G_u(z, \tau, T)$ is more widely applicable than the Durst and Miller factors, which are only applicable to some conditions such as a combination of $z=10$, level ground with few obstructions and limited averaging times. However, the approach adopted by Miller may be adopted as a unified approach

if $\mu_0(z, \tau, T)$ based on $L_u(z)/\bar{U}(z)$ is considered.

(2) Turbulence spectra and scales

Figure 5.10 shows differences in $G_u(z, \tau, T)$ due to $S_u(z, n)$ and $L_u(z)/\bar{U}(z)$. NBCCA'05/'10/'15, which adopts Type A with $T=3600$, significantly differs from any other representative group in that it drops sharply when τ exceeds 3. This result can be explained through Figure 5.9. For the minimum $L_u(z)/\bar{U}(z)$ (e.g., 28 for f10), the difference in $g_u(z, \tau, 3600)$ between $\tau=3$ and 60 is larger for Type A than for any other $S_u(z, n)$. This is due to differences in spectral shape as well as spectral strength covered by $\Phi(n, \tau, T)$, which is affected by $L_u(z)$. On the other hand, ASCE 7'98/'02/'05/'10/'16, which adopts Type B-1 with $T=3600$, shows some isolated cases. For the maximum $L_u(z)/\bar{U}(z)$ (e.g., 53 for f10), $G_u(z, \tau, 3600)$ does not exhibit the characteristic S-shaped forms as those seen with the minimum $L_u(z)/\bar{U}(z)$ (e.g. 2.9 for f10). This can happen when $\bar{U}(10)(2.9)$ is too low. Cao et al.(2009) presented similar results from their analyses of observational data with $\bar{U}(15)=5$ and 32 for $T=600$.

As discussed above, $G_u(z, \tau, T)$ is very practical over a wide range of $L_u(z)/\bar{U}(z)$ considering differences in spectral shape and peak frequency position, which are greatly affected by $S_u(z, n)$ and $L_u(z)/\bar{U}(z)$.

(3) Height and terrain situations

Figure 5.10 shows height effects on $G_u(z, \tau, T)$ with f10 and f200. f200 is lower at any τ than f10 although it shows similar shapes and trends to f10, regardless of $S_u(z, n)$ and T . However, differences between the two curves of f200 are definitely smaller than those in equivalent curves of f10. Figure 5.10 also shows terrain effects on $G_u(z, \tau, T)$ with f10 and s10. s10 is higher at any τ than f10 although it also shows similar shapes and trends to f10, regardless of $S_u(z, n)$ and T . Furthermore, differences between the two curves of s10 and equivalent curves of f10 are not as much as those between f10 and f200, except for the isolated cases in ASCE 7'98/'02/'05/'10/'16.

As discussed above, it makes sense to study $\bar{U}(z)$ at multiple heights including gradient heights, not to mention the reference height $z=10$, over level ground with few obstructions. However, differences in terrain roughness should be considered if $\bar{U}(z)$ is too low.

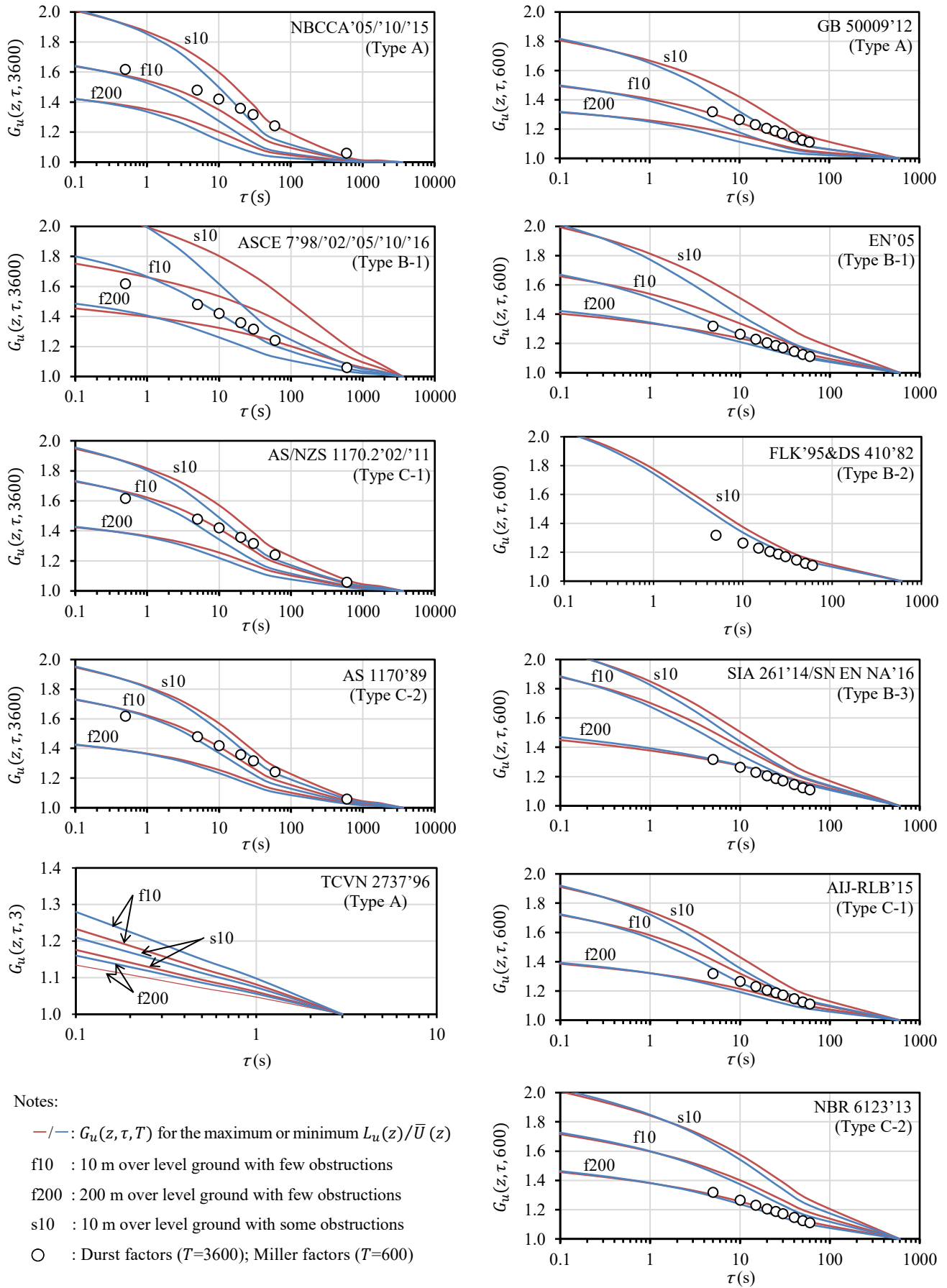


Figure 5.10 Wind speed conversion factors for 11 representative groups

Table 5.16 Peak factors and wind speed conversion factors at 10 m above level ground with few obstructions

T(s)	Type	Representative group	$g_u(10, \tau, T)$												$G_u(10, \tau, T)$																				
			$\tau(s)$												$\tau(s)$																				
			0.1	0.25	0.5	1	3	10	30	60	600	1800	3600	0.1	0.25	0.5	1	3	10	30	60	600	1800	3600											
3600	A	NBCCA'05/'10/'15	4.0	3.8	3.6	3.4	2.9	2.2	1.3	0.8	0.1	0.0	0.0	1.64	1.61	1.58	1.54	1.47	1.35	1.20	1.12	1.02	1.01	1.00	1.64	1.61	1.57	1.53	1.43	1.27	1.13	1.07	1.01	1.00	1.00
		ANSI A58.1'82/ ASCE 7'88	4.0	3.8	3.6	3.4	3.0	2.3	1.5	0.9	0.1	0.0	0.0	1.65	1.62	1.59	1.56	1.49	1.38	1.24	1.16	1.02	1.01	1.00	1.65	1.62	1.59	1.56	1.49	1.38	1.24	1.16	1.02	1.01	1.00
		NEN 6702'07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
		PNGS 1001.3'82	4.0	3.8	3.6	3.4	3.0	2.4	1.5	1.0	0.1	0.0	0.0	1.66	1.63	1.60	1.57	1.50	1.39	1.25	1.16	1.02	1.01	1.00	1.66	1.63	1.60	1.57	1.50	1.39	1.25	1.16	1.02	1.01	1.00
		ECP-201'12	4.0	3.8	3.6	3.3	2.8	2.1	1.4	1.0	0.3	0.1	0.0	1.75	1.71	1.67	1.63	1.53	1.40	1.27	1.20	1.05	1.01	1.00	1.75	1.71	1.67	1.63	1.53	1.40	1.27	1.20	1.05	1.02	1.00
		ASCE 7'98/'02/'05/ '10/'16	3.8	3.6	3.5	3.3	3.0	2.7	2.2	1.9	0.7	0.3	0.0	1.75	1.72	1.69	1.66	1.61	1.53	1.45	1.38	1.14	1.05	1.00	1.75	1.72	1.69	1.66	1.61	1.53	1.45	1.38	1.14	1.05	1.00
		ASCE 7'16	4.0	3.8	3.6	3.3	2.8	2.1	1.4	1.0	0.3	0.1	0.0	1.80	1.76	1.71	1.67	1.56	1.42	1.28	1.20	1.06	1.02	1.00	1.80	1.76	1.71	1.67	1.56	1.42	1.28	1.20	1.06	1.02	1.00
		SCBWRD'14	4.0	3.8	3.6	3.4	3.0	2.4	1.8	1.4	0.4	0.2	0.0	1.79	1.75	1.72	1.68	1.60	1.48	1.35	1.27	1.08	1.03	1.00	1.79	1.75	1.72	1.68	1.60	1.48	1.				

Table 5.17 Peak factors and wind speed conversion factors at 200 m above level ground with few obstructions

T(s)	Type	Representative group	$g_u(200, \tau, T)$												$G_u(200, \tau, T)$																																
			$\tau(s)$												$\tau(s)$																																
			0.1	0.25	0.5	1	3	10	30	60	600	1800	3600	0.1	0.25	0.5	1	3	10	30	60	600	1800	3600																							
3600	A	NBCCA'05/'10/'15	4.0	3.8	3.6	3.3	2.8	1.9	1.0	0.6	0.1	0.0	0.0	1.42	1.40	1.38	1.35	1.30	1.20	1.10	1.06	1.01	1.00	1.00	4.0	3.8	3.5	3.2	2.5	1.4	0.6	0.3	0.0	0.0	1.42	1.40	1.37	1.34	1.26	1.15	1.06	1.04	1.00	1.00	1.00		
		ANSI A58.1'82/ ASCE 7'88	4.0	3.8	3.6	3.4	3.0	2.3	1.5	0.9	0.1	0.0	0.0	1.42	1.40	1.39	1.37	1.32	1.25	1.16	1.10	1.01	1.00	1.00	4.0	3.8	3.6	3.3	2.7	1.7	0.8	0.5	0.1	0.0	0.0	1.43	1.40	1.38	1.35	1.29	1.18	1.09	1.05	1.01	1.00	1.00	
		NEN 6702'07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
		PNGS 1001.3'82	4.0	3.8	3.6	3.4	3.0	2.4	1.5	1.0	0.1	0.0	0.0	1.42	1.40	1.38	1.36	1.32	1.25	1.16	1.10	1.01	1.00	1.00	4.0	3.8	3.6	3.3	2.8	1.8	0.9	0.5	0.1	0.0	0.0	1.43	1.40	1.38	1.35	1.29	1.19	1.10	1.05	1.01	1.00	1.00	
	B-1	ECP-201'12	3.9	3.8	3.6	3.4	3.0	2.5	1.9	1.5	0.4	0.2	0.0	1.48	1.45	1.43	1.41	1.37	1.30	1.23	1.18	1.05	1.02	1.00	4.0	3.8	3.6	3.3	2.8	1.8	0.9	0.5	0.1	0.0	1.48	1.45	1.43	1.41	1.37	1.30	1.23	1.18	1.05	1.02	1.00		
		ASCE 7'98/'02/'05/ '10/'16	3.7	3.6	3.4	3.3	3.0	2.7	2.2	1.9	0.7	0.3	0.0	1.45	1.43	1.42	1.40	1.37	1.32	1.27	1.23	1.09	1.03	1.00	4.0	3.8	3.6	3.3	2.9	2.1	1.5	1.1	0.3	0.1	0.0	1.49	1.46	1.44	1.41	1.35	1.26	1.18	1.13	1.04	1.01	1.00	
		ASCE 7'16	4.0	3.8	3.6	3.4	3.0	2.4	1.8	1.3	0.4	0.2	0.0	1.48	1.46	1.44	1.41	1.36	1.29	1.21	1.16	1.05	1.02	1.00	4.0	3.8	3.6	3.4	2.9	2.2	1.5	1.1	0.3	0.1	0.0	1.48	1.46	1.44	1.41	1.35	1.27	1.18	1.14	1.04	1.02	1.00	
		SCBWRD'14	4.0	3.8	3.6	3.4	3.0	2.5	1.8	1.4	0.4	0.2	0.0	1.48	1.46	1.44	1.41	1.37	1.30	1.22	1.17	1.05	1.02	1.00	4.0	3.8	3.6	3.3	2.8	2.1	1.4	1.0	0.3	0.1	0.0	1.49	1.46	1.43	1.40	1.34	1.25	1.17	1.12	1.03	1.01	1.00	
		TCVN 2737'20	4.0	3.8	3.6	3.4	3.0	2.4	1.8	1.4	0.4	0.2	0.0	1.52	1.50	1.48	1.45	1.40	1.32	1.24	1.18	1.05	1.02	1.00	4.0	3.8	3.6	3.4	2.9	2.3	1.6	1.2	0.3	0.1	0.0	1.53	1.50	1.48	1.45	1.39	1.30	1.21	1.15	1.04	1.02	1.00	
		C-1	RSAREP'08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-							
	IS 875.3'15		4.0	3.8	3.6	3.4	3.0	2.4	1.6	1.1	0.3	0.1	0.0	1.39	1.37	1.36	1.34	1.30	1.23	1.16	1.11	1.03	1.01	1.00	4.0	3.8	3.6	3.4	2.9	2.1	1.3	0.9	0.2	0.1	0.0	1.40	1.38	1.36	1.33	1.29	1.21	1.13	1.09	1.02	1.01	1.00	
	AS/NZS 1170.2'02/'11		4.0	3.8	3.6	3.4	3.0	2.4	1.6	1.2	0.3	0.1	0.0	1.42	1.40	1.39	1.37	1.32	1.26	1.17	1.13	1.03	1.01	1.00	4.0	3.8	3.6	3.4	2.9	2.1	1.3	0.9	0.2	0.1	0.0	1.43	1.41	1.38	1.36	1.31	1.22	1.14	1.09	1.02	1.01	1.00	
	AS 1170.2'89		4.0	3.8	3.6	3.4	3.0	2.4	1.6	1.2	0.3	0.1	0.0	1.42	1.40	1.39	1.37	1.32	1.25	1.17	1.12	1.03	1.01	1.00	4.0	3.8	3.6	3.4	2.9	2.2	1.4	1.0	0.2	0.1	0.0	1.43	1.40	1.39	1.36	1.31	1.23	1.15	1.10	1.03	1.01	1.00	
	600	A	GB 50009'12	3.5	3.3	3.1	2.9	2.5	1.7	1.0	0.6	0.0	-	-	1.31	1.30	1.28	1.26	1.22	1.16	1.09	1.05	1.00	-	-	3.6	3.3	3.1	2.8	2.2	1.3	0.6	0.3	0.0	-	-	1.32	1.30	1.28	1.25	1.19	1.11	1.05	1.03	1.00	-	-
			SNiP 2.01.07'88/'05/ SP 20.13330'16	3.5	3.3	3.1	2.9	2.5	1.8	1.0	0.6	0.0	-	-	1.29	1.27	1.25	1.24	1.20	1.15	1.08	1.05	1.00	-	-	3.6	3.3	3.1	2.8	2.2	1.3	0.6	0.3	0.0	-	-	1.29	1.27	1.25	1.23	1.18	1.11	1.05	1.03	1.00	-	-
			SP 201.1325800'14	3.5	3.3	3.1	2.9	2.5	1.8	1.0	0.6	0.0	-	-	1.28	1.27	1.25	1.23	1.20	1.15	1.08	1.05	1.00	-	-	3.6	3.3	3.1	2.8	2.2	1.4	0.7	0.4	0.0	-	-	1.29	1.27	1.25	1.23	1.18	1.11	1.05	1.03	1.00	-	-
			NTCV'17	3.4	3.2	3.0	2.8	2.5	1.9	1.4	1.0	0.0	-	-	1.40	1.37	1.35	1.33	1.29	1.23	1.16	1.11	1.00	-	-	3.4	3.2	3.0	2.8	2.4	2.0	1.4	1.0	0.0	-	-	1.40	1.38	1.36	1.33	1.29	1.22	1.15	1.11	1.00	-	-
		EN'05	3.3	3.2	3.0	2.8	2.4	2.0	1.4	1.0	0.0	-	-	1.40	1.38	1.36	1.34	1.30	1.24	1.17	1.12	1.00	-	-	3.5	3.3	3.1	2.8	2.4	1.7	1.1	0.8	0.0	-	-	1.42	1.40	1.37	1.34	1.29	1.21	1.14	1.09	1.00	-	-	
			ENV'95	3.4	3.2	3.0	2.8	2.5	1.9	1.3	0.9	0.0	-	-	1.41	1.39	1.37	1.34	1.30	1.23	1.16	1.11	1.00	-	-	3.4	3.2	3.0	2.8	2.5	1.9	1.3	0.9	0.0	-	-	1.41	1.39	1.37	1.34	1.30	1.23	1.16	1.11	1.00	-	-
			PN EN NA'10	3.4	3.2	3.0	2.8	2.5	1.9	1.3	0.9	0.0	-	-	1.41	1.39	1.37	1.34	1.30	1.23	1.16	1.11	1.00	-	-	3.4	3.2	3.0	2.8	2.5	1.9	1.3	0.9	0.0	-	-	1.41	1.39	1.37	1.34	1.30	1.23	1.16	1.11	1.00	-	-
			SFS EN NA'16	3.4	3.2	3.0	2.8	2.5	1.9	1.3	0.9	0.0	-	-	1.41	1.39	1.37	1.34	1.30	1.23	1.16	1.11	1.00	-	-	3.4	3.2	3.0	2.8	2.5	1.9	1.3	0.9	0.0	-	-	1.41	1.39	1.37	1.34	1.30	1.23	1.16	1.11	1.00	-	-
		NS EN NA'09	3.4	3.2	3.0	2.8	2.5	1.9	1.3	0.9	0.0	-	-	1.41	1.39	1.37	1.34	1.30	1.23	1.16	1.11	1.00	-	-	3.4	3.2	3.0	2.8	2.5	1.9	1.3	0.9	0.0	-	-	1.41	1.39	1.37	1.34	1.30	1.23	1.16	1.11	1.00	-	-	
			BS EN NA'10	3.5	3.3	3.1	2.9	2.4	1.8	1.2	0.9	0.0	-	-	1.42	1.39	1.37	1.34	1.29	1.22	1.15	1.10	1.00	-	-	3.5	3.3	3.1	2.9	2.4	1.8	1.2	0.9	0.0	-	-	1.42	1.39	1.37	1.34	1.29	1.22	1.15	1.10	1.00	-	-
			UNI EN NA'13	3.4	3.2	3.0	2.8	2.5	1.9	1.3	0.9	0.0	-	-	1.41	1.39	1.37	1.34	1.30	1.23	1.16	1.11	1.00	-	-	3.5	3.2	3.1	2.9	2.4	1.9	1.2	0.9	0.0	-	-	1.43	1.31	1.29	1.27	1.23	1.18	1.13	1.09	1.00	-	-
NP EN NA'10			3.4	3.2	3.1	2.8	2.4	1.9	1.3	0.9	0.0	-	-	1.41	1.39	1.37	1.34	1.30	1.23	1.15	1.11	1.00	-	-	3.4	3.2	3.0	2.8	2.4	1.9	1.3	0.9	0.0	-	-	1.42	1.39	1.37	1.34	1.29	1.22	1.15	1.11	1.00	-	-	
ONORM EN NA'13			3.4	3.2	3.0	2.8	2.5	1.9	1.4	1.0	0.0	-	-	1.39	1.37	1.35	1.32	1.28	1.22	1.16	1.11	1.00	-	-	3.4	3.2	3.0	2.8	2.4	1.9	1.3	0.9	0.0	-	-	1.40	1.37	1.35	1.33	1.28	1.21	1.15	1.10	1.00	-	-	
NBN EN NA'10			3.4	3.2	3.0	2.8	2.5	1.9	1.3	0.9	0.0	-	-	1.41	1.39	1.37	1.34	1.30	1.23	1.16	1.11	1.00	-	-	3.4	3.2	3.0	2.8	2.5	1.9	1.3	0.9	0.0	-	-	1.41	1.39	1.37	1.34	1.30	1.23	1.15	1.11	1.00	-	-	
NF EN NA'08			3.4	3.2	3.0	2.8	2.5	1.9	1.4	1.0	0.0	-	-	1.41	1.38	1.36	1.34	1.29	1.23	1.16	1.12	1.00	-	-	3.5	3.3	3.1	2.9	2.4	1.8	1.2	0.8	0.0	-	-	1.42	1.39	1.37	1.34	1.29	1.22	1.14	1.10	1.00	-	-	
DIN EN NA'10			3.4	3.2	3.0	2.8	2.5	1.9	1.3	0.9	0.0	-	-	1.40	1.38	1.36	1.33	1.29	1.22	1.15	1.11	1.00	-	-	3.5	3.3	3.1	2.9	2.4	1.8	1.2	0.9	0.0	-	-	1.41	1.38	1.36	1.34	1.29	1.22	1.14	1.10	1.00	-	-	
NEN EN NA'11			3.4	3.2	3.0	2.8	2.5	1.9	1.3	0.9	0.0	-	-	1.49	1.47	1.44	1.41	1.36	1.28	1.19	1.14	1.00	-	-	3.4	3.2	3.0	2.8	2.4	1.9	1.3	0.9	0.0	-	-	1.50	1.47	1.44	1.41	1.35	1.27	1.18	1.13	1.00	-	-	
B-2			FLK'95&DS 410'82	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-								

Notes: upper row: maximum practical $L_u(z)/\bar{U}(z)$, lower row: minimum practical $L_u(z)/\bar{U}(z)$

Table 5.18 Peak factors and wind speed conversion factors at 10 m above level ground with some obstructions

T(s)	Type	Representative group	$g_u(10, \tau, T)$												$G_u(10, \tau, T)$																					
			$\tau(s)$												$\tau(s)$																					
			0.1	0.25	0.5	1	3	10	30	60	600	1800	3600	0.1	0.25	0.5	1	3	10	30	60	600	1800	3600												
3600	A	NBCCA'05/'10/'15	4.0	3.8	3.6	3.4	3.0	2.4	1.5	1.0	0.1	0.0	0.0	2.01	1.96	1.92	1.87	1.77	1.60	1.38	1.24	1.03	1.01	1.00	2.02	1.96	1.91	1.85	1.72	1.50	1.26	1.15	1.02	1.01	1.00	
		ANSI A58.1'82/ ASCE 7'88	4.0	3.8	3.6	3.4	3.1	2.5	1.7	1.1	0.2	0.1	0.0	1.91	1.87	1.83	1.79	1.71	1.57	1.39	1.26	1.04	1.01	1.00	1.91	1.87	1.83	1.79	1.71	1.57	1.39	1.26	1.04	1.01	1.00	
		NEN 6702'07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
		PNGS 1001.3'82	3.9	3.8	3.6	3.4	3.1	2.5	1.8	1.2	0.2	0.1	0.0	1.99	1.95	1.91	1.86	1.77	1.63	1.44	1.30	1.05	1.01	1.00	2.00	1.95	1.91	1.85	1.73	1.53	1.29	1.17	1.02	1.01	1.00	
	B-1	ECP-201'12	4.0	3.8	3.6	3.4	2.9	2.3	1.6	1.2	0.3	0.1	0.0	1.86	1.82	1.78	1.73	1.64	1.49	1.35	1.26	1.07	1.03	1.00	1.86	1.82	1.78	1.73	1.64	1.49	1.35	1.26	1.07	1.03	1.00	
		ASCE 7'98/'02/'05/ '10/'16	4.0	3.8	3.6	3.3	2.8	2.1	1.5	1.1	0.3	0.1	0.0	1.87	1.82	1.78	1.73	1.62	1.47	1.32	1.23	1.06	1.03	1.00	2.13	2.08	2.04	1.99	1.91	1.80	1.67	1.57	1.20	1.08	1.00	
		ASCE 7'16	4.0	3.8	3.6	3.3	2.8	2.1	1.4	1.0	0.3	0.1	0.0	2.20	2.13	2.07	1.99	1.84	1.62	1.41	1.30	1.08	1.03	1.00	2.19	2.13	2.08	2.02	1.89	1.70	1.50	1.38	1.11	1.04	1.00	
		ASCE 7'16	4.0	3.8	3.6	3.3	2.8	2.1	1.4	1.0	0.3	0.1	0.0	2.20	2.13	2.07	2.00	1.85	1.64	1.43	1.31	1.09	1.04	1.00	2.20	2.13	2.07	2.00	1.85	1.64	1.43	1.31	1.09	1.04	1.00	
		SCBWRD'14	4.0	3.8	3.6	3.4	3.0	2.4	1.8	1.3	0.4	0.2	0.0	2.19	2.13	2.08	2.02	1.90	1.72	1.53	1.40	1.12	1.05	1.00	2.19	2.13	2.08	2.02	1.90	1.72	1.53	1.40	1.12	1.05	1.00	
		SCBWRD'14	4.0	3.8	3.6	3.3	2.8	2.0	1.3	1.0	0.3	0.1	0.0	2.20	2.13	2.07	1.99	1.83	1.60	1.39	1.29	1.08	1.03	1.00	2.20	2.13	2.07	1.99	1.83	1.60	1.39	1.29	1.08	1.03	1.00	
		TCVN 2737'20	4.0	3.8	3.6	3.4	3.0	2.4	1.7	1.3	0.4	0.1	0.0	2.30	2.23	2.18	2.11	1.97	1.77	1.55	1.42	1.12	1.05	1.00	2.30	2.23	2.18	2.11	1.97	1.77	1.55	1.42	1.12	1.05	1.00	
		TCVN 2737'20	4.0	3.8	3.6	3.3	2.9	2.2	1.5	1.1	0.3	0.1	0.0	2.31	2.24	2.17	2.09	1.93	1.71	1.48	1.35	1.10	1.04	1.00	2.31	2.24	2.17	2.09	1.93	1.71	1.48	1.35	1.10	1.04	1.00	
	C-1	RSAEEP'08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
		IS 875.3'15	4.0	3.8	3.6	3.4	3.0	2.3	1.6	1.1	0.3	0.1	0.0	1.91	1.86	1.83	1.78	1.69	1.53	1.36	1.25	1.07	1.03	1.00	1.91	1.87	1.82	1.77	1.66	1.48	1.30	1.21	1.05	1.02	1.00	
		AS/NZS 1170.2'02/'11	4.0	3.8	3.6	3.4	3.0	2.4	1.6	1.2	0.3	0.1	0.0	1.95	1.90	1.86	1.82	1.72	1.57	1.39	1.28	1.07	1.03	1.00	1.95	1.90	1.86	1.82	1.72	1.57	1.39	1.28	1.07	1.03	1.00	
		AS/NZS 1170.2'02/'11	4.0	3.8	3.6	3.4	2.9	2.0	1.3	0.9	0.2	0.1	0.0	1.95	1.90	1.86	1.80	1.68	1.49	1.30	1.21	1.05	1.02	1.00	1.95	1.90	1.86	1.80	1.68	1.49	1.30	1.21	1.05	1.02	1.00	
	C-2	AS 1170.2'89	4.0	3.8	3.6	3.4	3.0	2.4	1.6	1.2	0.3	0.1	0.0	1.95	1.90	1.86	1.82	1.72	1.57	1.39	1.28	1.07	1.03	1.00	1.95	1.90	1.86	1.82	1.72	1.57	1.39	1.28	1.07	1.03	1.00	
		AS 1170.2'89	4.0	3.8	3.6	3.4	2.9	2.2	1.4	1.0	0.2	0.1	0.0	1.95	1.90	1.86	1.81	1.70	1.52	1.33	1.23	1.06	1.02	1.00	1.95	1.90	1.86	1.81	1.70	1.52	1.33	1.23	1.06	1.02	1.00	
	600	A	GB 50009'12	3.5	3.3	3.1	2.9	2.5	1.8	1.1	0.6	0.0	-	-	1.81	1.76	1.72	1.67	1.57	1.42	1.25	1.15	1.00	-	-	1.82	1.76	1.71	1.65	1.52	1.32	1.15	1.08	1.00	-	-
			SNiP 2.01.07'88/'05/ SP 20.13330'16	3.6	3.3	3.1	2.8	2.3	1.4	0.6	0.4	0.0	-	-	1.82	1.76	1.71	1.65	1.52	1.32	1.15	1.08	1.00	-	-	1.62	1.58	1.55	1.51	1.44	1.33	1.20	1.12	1.00	-	-
			SP 201.1325800'14	3.6	3.3	3.1	2.8	2.3	1.5	0.7	0.4	0.0	-	-	1.63	1.59	1.55	1.50	1.41	1.26	1.12	1.07	1.00	-	-	1.62	1.58	1.55	1.51	1.44	1.33	1.20	1.12	1.00	-	-
			SP 201.1325800'14	3.5	3.3	3.1	2.9	2.5	1.9	1.1	0.7	0.0	-	-	1.62	1.58	1.55	1.51	1.44	1.33	1.20	1.12	1.00	-	-	1.62	1.58	1.55	1.51	1.44	1.33	1.20	1.12	1.00	-	-
		B-1	NTCV'17	3.5	3.3	3.1	2.9	2.3	1.5	0.7	0.4	0.0	-	-	1.63	1.59	1.55	1.51	1.41	1.27	1.13	1.07	1.00	-	-	1.63	1.59	1.55	1.51	1.41	1.27	1.13	1.07	1.00	-	-
			NTCV'17	3.5	3.3	3.1	2.8	2.4	1.7	1.1	0.8	0.0	-	-	2.02	1.95	1.89	1.82	1.69	1.50	1.32	1.22	1.00	-	-	2.02	1.95	1.89	1.82	1.67	1.47	1.29	1.20	1.00	-	-
EN'05			3.5	3.3	3.1	2.9	2.4	1.8	1.2	0.8	0.0	-	-	1.99	1.93	1.88	1.81	1.69	1.51	1.33	1.23	1.00	-	-	1.99	1.93	1.88	1.81	1.69	1.51	1.33	1.23	1.00	-	-	
EN'05			3.5	3.3	3.0	2.7	2.1	1.4	0.8	0.6	0.0	-	-	2.01	1.93	1.86	1.77	1.60	1.39	1.23	1.16	1.00	-	-	2.01	1.93	1.86	1.77	1.60	1.39	1.23	1.16	1.00	-	-	
ENV'95			3.5	3.3	3.1	2.9	2.4	1.8	1.2	0.8	0.0	-	-	1.99	1.93	1.88	1.81	1.69	1.52	1.34	1.24	1.00	-	-	1.99	1.93	1.88	1.81	1.69	1.52	1.34	1.24	1.00	-	-	
ENV'95			3.5	3.3	3.1	2.9	2.4	1.8	1.2	0.8	0.0	-	-	1.99	1.93	1.88	1.81	1.69	1.52	1.34	1.24	1.00	-	-	1.99	1.93	1.88	1.81	1.69	1.52	1.34	1.24	1.00	-	-	
PN EN NA'10			3.5	3.3	3.1	2.8	2.3	1.6	1.0	0.7	0.0	-	-	2.01	1.94	1.88	1.80	1.66	1.47	1.29	1.20	1.00	-	-	2.01	1.94	1.88	1.80	1.66	1.47	1.29	1.20	1.00	-	-	
PN EN NA'10			3.5	3.3	3.1	2.8	2.3	1.6	1.0	0.7	0.0	-	-	2.01	1.94	1.88	1.80	1.65	1.45	1.28	1.19	1.00	-	-	2.01	1.94	1.88	1.80	1.65	1.45	1.28	1.19	1.00	-	-	
SFS EN NA'16			3.5	3.3	3.1	2.8	2.3	1.7	1.1	0.7	0.0	-	-	2.00	1.94	1.88	1.81	1.67	1.48	1.30	1.21	1.00	-	-	2.00	1.94	1.88	1.81	1.67	1.48	1.30	1.21	1.00	-	-	
SFS EN NA'16			3.5	3.3	3.1	2.8	2.3	1.7	1.1	0.7	0.0	-	-	2.00	1.94	1.88	1.81	1.67	1.48	1.30	1.21	1.00	-	-	2.00	1.94	1.88	1.81	1.67	1.48	1.30	1.21	1.00	-	-	
NS EN NA'09			3.5	3.3	3.1	2.8	2.3	1.7	1.0	0.7	0.0	-	-	2.00	1.94	1.88	1.81	1.67	1.47	1.30	1.20	1.00	-	-	2.00	1.94	1.88	1.81	1.67	1.47	1.30	1.20	1.00	-	-	
NS EN NA'09			3.5	3.3	3.1	2.8	2.2	1.5	0.9	0.6	0.0	-	-	2.01	1.94	1.87	1.79	1.64	1.44	1.27	1.18	1.00	-	-	2.01	1.94	1.87	1.79	1.64	1.44	1.27	1.18	1.00	-	-	
BS EN NA'10			3.5	3.3	3.1	2.8	2.3	1.7	1.1	0.7	0.0	-	-	1.96	1.89	1.84	1.77	1.64	1.46	1.29	1.20	1.00	-	-	1.96	1.89	1.84	1.77	1.64	1.46	1.29	1.20	1.00	-	-	
BS EN NA'10			3.5	3.3	3.1	2.8	2.3	1.6	1.0	0.7	0.0	-	-	1.96	1.89	1.83	1.76	1.61	1.42	1.26	1.18	1.00	-													

5.5 Conclusions

This chapter explored the unified approach for practically comparing reference wind speeds in national border areas, while ensuring respect for atmospheric boundary layer models in laws, regulations, codes, and standards of each country to enhance the effectiveness of this initiative. This approach involves the theory of deriving the statistical distribution of the maxima of a stationary random function. First, we reviewed the theory applied to averaging time conversions of wind speeds. Next, we examined U_{ref} or q_{ref} , $K_u(z)$, $I_u(z)$, $S_u(z, n)$, and $L_u(z)$ in 176 codes and standards and classified them into 37 representative groups. Then, we computed $g_u(z, \tau, T)$ for obtaining wind speeds with various averaging times considering 11 combinations of $S_u(z, n)$ and T , based on the reviewed theory. Finally, we discussed some practical considerations in comparisons of reference wind speeds in national border areas by demonstrating wind speed conversion factors as a practical application example. The results are summarized as follows:

(1) Specifications of atmospheric boundary layer models

- 164 codes and standards define U_{ref} or q_{ref} . Of these, 113 codes and standards define $K_u(z)$, $I_u(z)$, $S_u(z, n)$, and $L_u(z)$ in mathematical forms.
- 113 codes and standards define any of 3 seconds (including 20 seconds with a conversion factor), 1 minute (including fastest-mile), 10 minutes, or 1 hour and any of 1 hour, 10 minutes, or 3 seconds as τ and T , respectively.
- Some codes or standards define U_{ref} or q_{ref} as instantaneous values updated every short time interval. Such codes or standards do not define any of $I_u(z)$, $S_u(z, n)$, or $L_u(z)$.
- 113 codes and standards are aggregated into 37 representative groups, considering $I_u(z)$, $S_u(z, n)$, $L_u(z)$, and T . These groups are further classified into 11 combinations of $S_u(z, n)$ and T .

(2) Characteristics of computed peak factors

- The curves of $g_u(z, \tau, T)$ show a convex upward trend regardless of any spectral types, T , or τ . The longer τ is, the lower the maximum $g_u(z, \tau, T)$ is and the higher $L_u(10)/\bar{U}(10)$ at that point is.
- The maxima of $g_u(z, \tau, T)$ with the same T show almost the same values regardless of any spectral types. $g_u(z, \tau, 3600)$ is 3.8, 3.1, 2.1, and 0.9 at $\tau=0.25, 3, 60$, and 600, respectively. $g_u(z, \tau, 600)$ is 3.3, 2.5, and 1.2 at $\tau=0.25, 3$, and 60, respectively. Here, $\tau=0.25$ assumes instantaneous wind speeds.
- The spectra with the same β have a recognizable regularity in $L_u(10)/\bar{U}(10)$ at the maximum point of $g_u(z, \tau, T)$, as with turbulence spectra. The curves of $g_u(z, \tau, T)$ overlap each other with coordinate transformations that correspond to specific ratios.
- The asymptotic approximation of $g_u(z, \tau, T)$ is adequate for estimating $g_u(z, \tau, T)$ with small τ/T and low $L_u(z)/\bar{U}(z)$ such as strong gusts of wind.
- The curves of $g_u(z, \tau, T)$ provide practical results overall, regardless of any spectral types, T or τ , as compared with previous study results.
- $g_u(z, \tau, T)$ enables effortless conversions of wind speeds into different specifications using only

$L_u(z)/\bar{U}(z)$. However, a return period needs to be considered separately.

(3) Practical considerations in comparisons of reference wind speeds

- $G_u(z, \tau, T)$ exhibits characteristic S-shaped forms with a monotonic increase and becomes approximately equal at maximum and minimum $L_u(z)/\bar{U}(z)$ as τ decreases.
- $G_u(z, \tau, T)$ is larger for the maximum $L_u(z)/\bar{U}(z)$ than for the minimum $L_u(z)/\bar{U}(z)$ at high τ . The magnitude of this relationship is reversed as τ decreases.
- The Durst and Miller factors are understood to be applicable to specific conditions, such as a combination of $z=10$, level ground with few obstructions, and limited averaging times.
- $G_u(z, \tau, T)$ is very practical over a wide range of $L_u(z)/\bar{U}(z)$, considering differences in spectral shape and peak frequency position, which are greatly affected by $S_u(z, n)$ and $L_u(z)/\bar{U}(z)$.
- The discussed approach is adequate for a unified approach due to its broad applicability. However, U_{ref} or q_{ref} should be compared over multiple terrain roughnesses or at multiple heights above ground in national border areas, respecting different specifications from country to country.

This chapter contributed to a specific objective of this thesis: reviewing the theory for computing peak factors for obtaining wind speeds with various averaging times and discussing practical considerations in comparisons of reference wind speeds in national border areas through practical application examples.

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6 CONCLUDING REMARKS

This thesis contributed to the five specific objectives set at the beginning of this study, as clarified in Chapter 1 and concluded in Chapters 2 to 5. Consequently, it contributed to the overall purpose of this thesis: exploring a unified approach applicable to practically comparing reference wind speeds in national border areas, while ensuring respect for laws, regulations, codes, and standards utilized in countries around the world to enhance the effectiveness of this initiative.

In this chapter, we summarize this thesis from three aspects: quantity, quality, and value creation based on the findings from Chapters 1 to 5.

6.1 Accomplishments in the Thesis

In the quantitative aspect, this thesis succeeded in making the following accomplishments.

Chapter 1: Introduction

This chapter clarified the issues and problems to be discussed in this thesis through literature reviews, and succeeded in:

- setting the final goals of this study,
- stating the overall purpose, specific objectives of this thesis,
- describing the originality and value of this thesis, and
- outlining the structure and scope of this thesis.

Consequently, it contributed to clarifying the issues and problems to be discussed in this thesis through literature reviews on international cooperation in the field of wind-resistant design of buildings.

Chapter 2: Laws, Regulations, Codes and Standards

This chapter studied ongoing facts about legal and regulatory frameworks, as well as codes and standards for wind-resistant design of buildings in all 195 countries, which are 193 of which are member states of the United Nations (UN) and two of which are observer states at the UN General Assembly, and succeeded in:

- studying a huge amount of relevant information considering both three levels of jurisdictional areas covered in this thesis and three challenges found out in this chapter,
- summarizing laws, regulations, codes, and standards for each country although there were some differences in the amount of information, and
- providing the fundamental information for analyses in the subsequent chapters.

Consequently, it contributed to summarizing worldwide information on legal and regulatory frameworks, including provisions on wind-resistant design of buildings, as well as codes and standards for wind-resistant design of buildings.

Chapter 3: Worldwide Status on Legal and Regulatory Frameworks

This chapter discussed the worldwide status on legal and regulatory frameworks in 137 countries identified in Chapter 2, focusing on three types of provisions: wind-resistant design liability, wind load calculation methods, and reference wind speeds or pressures, and succeeded in:

- studying the worldwide status of legal and regulatory frameworks for each type of provision from the standpoint of jurisdictions and requirements.
- examining worldwide challenges on the establishment of legal and regulatory frameworks from three perspectives: human or economic damage from storms, and economic developments of countries, and
- discussing the future status on legal and regulatory frameworks from national or subnational initiatives of the remaining 58 countries without them.

Consequently, it contributed to revealing the worldwide status on legal and regulatory frameworks, including provisions on wind-resistant design of buildings, and discussing challenges in establishing them.

Chapter 4: Worldwide Trends of Codes and Standards

This chapter discussed worldwide trends of 176 codes and standards in 190 countries to compile an overall picture of codes and standards worldwide from the perspective of atmospheric boundary layer models, and succeeded in:

- reviewing atmospheric boundary layer models as engineering models for categorizing codes and standards,
- defining classification categories and classifying the models into three categories based on their extent of spread to other regions or countries, as well as 22 subcategories based on their country or international organization of origin,
- studying current worldwide trends of atmospheric boundary layer models of 176 codes and standards, and
- discussing future trends of primarily the EU and US models from regional or national initiatives in regions or countries in transition phases.

Consequently, it contributed to revealing worldwide trends of codes and standards for wind-resistant design of buildings and discussing future trends.

Chapter 5: Wind Speed Conversions to Various Averaging Times

This chapter explored the unified approach for practically comparing reference wind speeds in national border areas, while ensuring respect for atmospheric boundary layer models in laws, regulations, codes, and standards of each country to enhance the effectiveness of this initiative, and succeeded in:

- reviewing the theory applied to averaging time conversions of wind speeds, in which the statistical distribution of the maxima of a stationary random function is derived,
- studying U_{ref} or q_{ref} , $K_u(z)$, $I_u(z)$, $S_u(z, n)$ and $L_u(z)$ in 176 codes and standards and classified into 37 representative groups,
- computing $g_u(z, \tau, T)$ for obtaining wind speeds with various averaging times considering 11 combinations of $S_u(z, n)$ and T , and
- discussing some practical considerations in conversions and comparisons of reference wind speeds in national border areas by demonstrating wind speed conversion factors as a practical application example.

Consequently, it contributed to reviewing the theory for computing peak factors for obtaining wind speeds with various averaging times and discussing practical considerations in comparisons of reference wind speeds in national border areas through practical application examples.

6.2 Findings from the Thesis

In the qualitative aspect, this thesis succeeded in revealing the following findings.

Chapter 1: Introduction

This chapter suggested that it was highly strategic, vital, and unique in the subject of wind-resistant design of buildings, in terms of:

- focusing on legal and regulatory frameworks and discussing the worldwide status of legal and regulatory frameworks, not to mention worldwide trends of codes and standards.
- exploring a unified approach for obtaining wind speeds with various averaging times, while ensuring respect for formulae or figures defined in laws, regulations, codes, or standards, instead of analyzing observational data.

Chapter 2: Laws, Regulations, Codes and Standards

(1) Study policy

This chapter succeeded in covering all 195 countries, 193 of which are member states of the UN and two of which are observer states at the UN General Assembly, by:

- considering three levels of jurisdictional areas: countries (first level), states or provinces (second level), and cities (third level),
- conducting email interviews with consultants, researchers, or officials, if necessary, in addition to obtaining online information,
- fully utilizing Google Search and Translate to obtain and understand online information, and
- undergoing a process of trial and error in three phases: 1) obtaining relevant information from other countries, 2) correctly scanning the contents of the information, and 3) accurately understanding them.

(2) Legal and regulatory frameworks

This chapter also revealed the following findings.

- At least 137 countries, accounting for 70% of the total, have established legal and regulatory frameworks including provisions on wind-resistant design of buildings.
- At most 58 countries, accounting for 30% of the total, have not established legal and regulatory frameworks including provisions on wind-resistant design of buildings. Of these, African countries account for most of them.
- Developed countries do not always enact legislation for wind-resistant design of buildings (e.g., Belgium).
- Developing countries do not always establish legal and regulatory frameworks akin to those of closely related developed countries (e.g., Ukraine).
- Some countries incorporate provisions on wind-resistant design of buildings into regulations for seismic-resistant design of buildings (e.g., Cuba).

Chapter 3: Worldwide Status on Legal and Regulatory Frameworks

This chapter revealed the following findings.

(1) Worldwide status on legal and regulatory frameworks

- 137 countries, accounting for 70% of the total, at least mention or imply wind-resistant design liability within legal and regulatory frameworks. Of these, 121 and 115 countries, accounting for 62% and 59% of the total, also define wind load calculation methods and reference wind speeds or pressures therein, respectively.
- 110 and 27 countries, accounting for 56% and 14 % of the total, mention or imply wind-resistant design liability at the national and subnational levels, respectively.
- 16 countries mention or imply only wind-resistant design liability, and another set of 16 countries accept multiple systems in either wind load calculation methods or reference wind speeds or pressures. Both account for 8.2% of the total.

(2) Human damage from storms

- No or small loss areas spread across Africa and Europe. Large loss areas extend to the Americas and Asia with tropical cyclone areas.
- The level of maximum human damage from storms is not always a decisive factor, but it does have some influence on the establishment of laws or regulations related to wind-resistant design of buildings.
- The number of countries establishing laws or regulations at the national level is approximately the same regardless of human damage level. However, the number of countries establishing laws or regulations at subnational levels increases with the rise of human damage level.

(3) Economic damage from storms

- No/low loss areas spread across Africa. Extreme loss areas extend not only to the Americas and Asia with tropical cyclone areas but also to Europe.
- Economic damage from storms does not necessarily directly lead to the establishment of laws or regulations.

(4) Economic development of countries

- Low income areas spread across Africa. High income areas extend to Europe.
- The establishment of laws or regulations requires at least the level of lower middle income. Additionally, more financial or technical support for lower middle income countries, which define only wind-resistant design liability, is highly effective for the full establishment of laws or regulations.
- Countries with higher economic development levels can establish laws or regulations at subnational levels or accept multiple systems.

(5) National or subnational initiatives

- The number of countries with legal and regulatory frameworks should continue to increase gradually rather than dramatically. At least 10 countries, accounting for 5.1% of the total, are taking initiatives

to establish a legal and regulatory framework including wind-resistant safety requirements.

Chapter 4: Worldwide Trends of Codes and Standards

This chapter revealed the following findings.

(1) Category classification

- Atmospheric boundary layer models are classified into three categories: WW, RG, and DS, based on their extent of spread to other regions or countries, as well as 22 subcategories including: AU, BD, BR, CA, NL, EU, FR, DE, IN, IO, IT, JP, MX, PE, PT, RU, ZA, CH, UK, US, YU, and DS, based on their country or international organization of origin.
- Twelve models: AU, BD, CA, NL, EU, FR, DE, IO, PT, RU, UK, and US, which are accepted in multiple regions of Africa, the Americas, Asia, Europe, and Oceania, are classified into the category of WW models. Nine models: BR, IN, IT, JP, MX, PE, ZA, CH, and YU, which are accepted only in any region of Africa, the Americas, Asia, Europe, or Oceania, are classified into the category of RG models.
- Of the WW models, two models: UK and US are accepted in all five regions, and two models: EU and FR are accepted in three regions: Africa, Asia, and Europe. The remaining eight models: AU, BD, CA, NL, DE, IO, PT, and RU are accepted in two regions including their own region.
- Three models: IO, PE, and YU, which consist of a single set of models, do not define any of the three components: wind speed profile, turbulence intensity profile, or turbulence spectrum. 10 models: NL, FR, DE, PT, UK, US, IN, MX, ZA, and DS, which consist of multiple sets of models, have at least one model that does not define any of the three components.
- The DS models consist of 31 models in 25 countries, including three countries with multiple models: Nigeria with two models, China with five models, and Vietnam with two models. The parallel use with the WW and RG models is also accepted in 11 countries: Dominican Republic, Chile, Mongolia, Indonesia, Thailand, Vietnam, Iran, Syria, Denmark (Greenland), Albania, and Greece. There are no DS models in Oceania.

(2) Worldwide trends

- Two models: EU and US are the most widely accepted worldwide, being adopted in 43 countries, accounting for 22.1% of the total. They are followed by four models: UK, FR, AU, and RU, whose numbers of countries and proportions to the total are 25, 25, 13, and 12, and 12.8%, 12.8%, 6.7%, and 6.2%, respectively.
- Four models: EU, US, FR, and AU have a definite influence particularly on four regions: Europe, the Americas, Africa, and Oceania, respectively. Five models: EU, RU, UK, US, and DS are also widely accepted in Asia.
- The FR models are commonly accepted in African countries without wind-resistant design liability. The UK models are more widely accepted in Asia than in Europe. The DS models are mostly developed in Asian and European countries.
- Thirteen models: CA, NL, DE, PT, RU, BR, IN, IT, JP, MX, PE, CH, and YU are almost the same number of countries with or without wind-resistant design liability.

(3) Regional or national initiatives

- Two models: EU and US are expected to become more polarized in terms of the number of countries. Meanwhile, it is hard to imagine that any other models will be more acceptable than ever before.
- The EU and US models are not always dominant worldwide regarding the area of countries. Future trends in Russia or its neighboring countries, which are expected to transition to the EU models, definitely have a major impact on the spread of the EU models.

Chapter 5: Wind Speed Conversions to Various Averaging Times

This chapter revealed the following findings.

(1) Specifications of atmospheric boundary layer models

- 164 codes and standards define U_{ref} or q_{ref} . Of these, 113 codes and standards define $K_u(z)$, $I_u(z)$, $S_u(z, n)$, and $L_u(z)$ in mathematical forms.
- 113 codes and standards define any of 3 seconds (including 20 seconds with a conversion factor), 1 minute (including fastest-mile), 10 minutes, or 1 hour and any of 1 hour, 10 minutes, or 3 seconds as τ and T , respectively.
- Some codes or standards define U_{ref} or q_{ref} as instantaneous values updated every short time interval. Such codes or standards do not define any of $I_u(z)$, $S_u(z, n)$, or $L_u(z)$.
- 113 codes and standards are aggregated into 37 representative groups, considering $I_u(z)$, $S_u(z, n)$, $L_u(z)$, and T . These groups are further classified into 11 combinations of $S_u(z, n)$ and T .

(2) Characteristics of computed peak factors

- The curves of $g_u(z, \tau, T)$ show a convex upward trend regardless of any spectral types, T , or τ . The longer τ is, the lower the maximum $g_u(z, \tau, T)$ is and the higher $L_u(10)/\bar{U}(10)$ at that point is.
- The maxima of $g_u(z, \tau, T)$ with the same T show almost the same values regardless of any spectral types. $g_u(z, \tau, 3600)$ is 3.8, 3.1, 2.1, and 0.9 at $\tau=0.25, 3, 60$, and 600, respectively. $g_u(z, \tau, 600)$ is 3.3, 2.5, and 1.2 at $\tau=0.25, 3$, and 60, respectively. Here, $\tau=0.25$ assumes instantaneous wind speeds.
- The spectra with the same β have a recognizable regularity in $L_u(10)/\bar{U}(10)$ at the maximum point of $g_u(z, \tau, T)$, as with turbulence spectra. The curves of $g_u(z, \tau, T)$ overlap each other with coordinate transformations that correspond to specific ratios.
- The asymptotic approximation of $g_u(z, \tau, T)$ is adequate for estimating $g_u(z, \tau, T)$ with small τ/T and low $L_u(z)/\bar{U}(z)$ such as strong gusts of wind.
- The curves of $g_u(z, \tau, T)$ provide practical results overall, regardless of any spectral types, T or τ , as compared with previous study results.
- $g_u(z, \tau, T)$ enables effortless conversions of wind speeds into different specifications using only $L_u(z)/\bar{U}(z)$. However, a return period needs to be considered separately.

(3) Practical considerations in comparisons of reference wind speeds

- $G_u(z, \tau, T)$ exhibits characteristic S-shaped forms with a monotonic increase and becomes approximately equal at maximum and minimum $L_u(z)/\bar{U}(z)$ as τ decreases.
- $G_u(z, \tau, T)$ is larger for the maximum $L_u(z)/\bar{U}(z)$ than for the minimum $L_u(z)/\bar{U}(z)$ at high τ . The

magnitude of this relationship is reversed as τ decreases.

- The Durst and Miller factors are understood to be applicable to specific conditions, such as a combination of $z=10$, level ground with few obstructions, and limited averaging times.
- $G_u(z, \tau, T)$ is very practical over a wide range of $L_u(z)/\bar{U}(z)$, considering differences in spectral shape and peak frequency position, which are greatly affected by $S_u(z, n)$ and $L_u(z)/\bar{U}(z)$.
- The discussed approach is adequate for a unified approach due to its broad applicability. However, U_{ref} or q_{ref} should be compared over multiple terrain roughnesses or at multiple heights above ground in national border areas, respecting different specifications from country to country.

6.3 Outcomes of the Thesis

In the value creation aspect, this thesis is strongly expected to contribute to:

- serving as a valuable reference for countries and regions with incomplete legal and regulatory frameworks and aiding them in establishing more complete ones,
- serving as a valuable reference for countries and regions with incomplete code and standard systems and assisting them in developing more complete ones,
- acting as a valuable compass for determining the necessary education and training of human resources in the field of wind-resistant design of buildings,
- enabling effortless conversions of wind speeds into different specifications,
- assisting in figuring out differences in reference wind speeds in national border areas,
- aiding in developing a world map based on reference wind speeds, while respecting codes or standards of each country, and
- further promoting collaborations between neighboring countries to solve technical challenges in setting reference wind speeds.

APPENDIX 1 LIST OF JOURNAL PAPERS, TECHNICAL NOTES OR CONFERENCE PAPER

The journal papers, technical notes, and conference paper related to this doctoral thesis are listed below.

(1) Journal papers

- Hayakawa, A., Matsui, M., and Tamura, Y. 2022. “Worldwide Status on Legal and Regulatory Frameworks with Provisions Related to Wind-resistant Design of Buildings.” *Journal of Wind Engineering, JAWE*, 47(2(171)), 5(1)-17(13).
- Hayakawa, A. 2023. “Conversion of Wind Speeds to Various Averaging Times Based on 176 Codes and Standards for Wind-resistant Design of Buildings”, *Journal of Wind Engineering, JAWE*, 48(3(176)),1(1)-13(13).

(2) Technical notes

- Hayakawa, A., Matsui, M., and Tamura, Y. 2021. “Legal and Regulatory Frameworks of 195 Countries around the World with Provisions related to Wind-Resistant Design of Buildings, Part 1. Africa, Americas and Asia.” *Wind Engineers, JAWE*, 46(4(169)), 420(78)-439(97).
- Hayakawa, A., Matsui, M., and Tamura, Y. 2021. “Legal and Regulatory Frameworks of 195 Countries around the World with Provisions related to Wind-Resistant Design of Buildings, Part 2. Europe and Oceania.” *Wind Engineers, JAWE*, 46(4(169)), 440(98)-454(112).
- Hayakawa, A., Matsui, M., and Tamura, Y. 2021. “Codes and Standards of 195 Countries around the World for Wind-Resistant Design of Buildings. Part 1. Countries with the Legal and Regulatory Framework.” *Wind Engineers, JAWE*, 46(4(169)), 455(113)-474(132).
- Hayakawa, A., Matsui, M., and Tamura, Y. 2022. “Codes and Standards of 195 Countries around the World for Wind-Resistant Design of Buildings. Part 2. Countries without a Legal and Regulatory Framework.” *Wind Engineers, JAWE*, 47(2(171)), 83(83)-95(95).

(3) Conference paper

- Hayakawa, A., Matsui, M., and Tamura, Y. 2017. “Popular Trend of Wind Loading Codes and Standards in the World. [Japanese]”, *Summaries of Technical Papers of Annual Meeting, AIJ, Chugoku, Japan, August 2017, No. 20087*, pp.73-74.

APPENDIX 2 WORLD LIST OF LAWS, REGULATIONS, CODES OR STANDARDS OF 195 COUNTRIES

A total of more than 670 laws, regulations, codes, and standards from 195 countries are listed in this Appendix. This Appendix has been posted on the website (URL: <https://werc.t-kougei.ac.jp/TPUdatabase.html>) of the Wind Engineering Research Center, Tokyo Polytechnic University, and will be regularly updated.

- ABCB (Australian Building Codes Board). 2003. *Building Code of Australia 1996*. Canberra, Australia.
- ABCB (Australian Building Codes Board). 2019. *National Construction Code - Volumes One. Building Code of Australia 2019*. Canberra, Australia.
- ABCi (Authority for Building Control and Construction Industry). 2017. *Building Guidelines and Requirements*. PBD 12:2017, Bandar Seri Begawan, Brunei.
- ABNT (Associação Brasileira de Normas Técnicas). 1988. *Forças devidas ao vento em edificações [Portuguese]*. NBR 6123:1988, Rio de Janeiro, Brasil.
- ABNT (Associação Brasileira de Normas Técnicas). 2013. *Forças devidas ao vento em edificações [Portuguese]*. Versao Corrigida 2:2013, ABNT NBR 6123:1988, Rio de Janeiro, Brasil.
- Act on Spatial Planning and Building Regulations (Building Act) [Slovak]*. 1976. No. 50/1976 Coll., Prague, Czechoslovakia.
- AFNOR (French Association for Standardization). 2008. *Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions - National annex to NF EN 1991-1-4:2005 - General actions - Wind actions [French]*. NF EN 1991-1-4/NA:2008-03, Saint-Denis, France.
- AFNOR (French Association for Standardization). 2012. *Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions - National annex to NF EN 1991-1-4:2005 - General actions - Wind actions [French]*. NF EN 1991-1-4/NA/A2:2012-09, Saint-Denis, France.
- AGD (Attorney-General's Department). 1992a. *Local Government (Transition) Ordinance 1992*. No.6, Canberra, Australia.
- AGD (Attorney-General's Department). 1992b. *Local Government (Transition) Ordinance 1992*. No.4, Canberra, Australia.
- AGIES (Guatemalan Association of Structural and Seismic Engineering). 2010. *Demandas Estructurales, Condiciones de Sitio y Niveles de Proteccion [Spanish]*. AGIES NSE 2-10, Santa Catarina Pinula, Guatemala.
- AIDAB (Australian International Development Assistance Bureau). 1990a. *National Building Code for Solomon Islands*. Suva, Fiji.
- AIDAB (Australian International Development Assistance Bureau). 1990b. *National Building Code for Tuvalu*. Suva, Fiji.
- AIJ (Architectural Institute of Japan). 1993. *Recommendations for Loads of Buildings [Japanese]*. Tokyo, Japan.
- AIJ (Architectural Institute of Japan). 2015. *Recommendations for Loads of Buildings [Japanese]*. Tokyo, Japan.
- ALR (Alands landskapsregering). 2015. *Landskapsforordning om Alands byggbestammelsesamling [Swedish]*. No 5, Mariehamn, Aland Islands.
- ANSA (Afghanistan National Standard Authority). 2012. *Afghan Structural Code*. Kabul, Afghanistan.
- ANSI (American National Standards Institute). 1982. *Minimum Design Loads for Buildings and Other Structures*. ANSI A58.1-1982, New York, United States.
- ARXKOM (State Committee for Urban Planning and Architecture). 2015. *Loads and Effects. Design Norms [Azerbaijani]*. AzDTN 2.1-1, Baku, Azerbaijan.
- AS (Standards Australia). 1993. *Minimum design loads on structures (known as the SAA Loading Code)*,

- Part 2: Wind loads.* AS 1170.2-1989, Sydney, Australia.
- ASA (American Standards Association). 1955. *Minimum Design Loads in Buildings and Other Structures*. ANSI A58.1-1955, New York, United States.
- ASCE (American Society of Civil Engineers). 1990. *Minimum Design Loads for Buildings and Other Structures*. ANSI/ASCE 7-88, Reston, United States.
- ASCE (American Society of Civil Engineers). 1998. *Minimum Design Loads for Buildings and Other Structures*. ASCE 7-98, Reston, United States.
- ASCE (American Society of Civil Engineers). 2002. *Minimum Design Loads for Buildings and Other Structures*. SEI/ASCE 7-02, Reston, United States.
- ASCE (American Society of Civil Engineers). 2005. *Minimum Design Loads for Buildings and Other Structures*. ASCE/SEI 7-05, Reston, United States.
- ASCE (American Society of Civil Engineers). 2010. *Minimum Design Loads for Buildings and Other Structures*. ASCE/SEI 7-10, Reston, United States.
- ASCE (American Society of Civil Engineers). 2016. *Minimum Design Loads for Buildings and Other Structures*. ASCE/SEI 7-16, Reston, United States.
- ASEP (Association of Structural Engineers of the Philippines). 2015. *National Structural Code of the Philippines*. NSCP C101-15, Quezon City, Philippines.
- ASI (Austrian Standards Institute). 2013. *Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions - National Specifications concerning ONORM EN 1991-1-4 and national supplements [German]*. ONORM B 1991-1-4:2013, Vienna, Austria.
- ASIA (Asociacion Salvadorena de Ingenieros y Arquitectos). 1997. *Norma Tecnica para Diseno por Viento y sus Comentarios [Spanish]*. San Salvador, El Salvador.
- ASN (Association Senegalaise de Normalisation). 2008. *Regles Senevent: Methode d'evaluation des efforts du vent sur les constructions au Senegal [French]*. NS 02-058:2008, Dakar, Senegal.
- AS/NZS (Standards Australia and Standards New Zealand). 2002. *Structural design actions, Part 2: Wind actions*. AS/NZS 1170.2:2002, Sydney, Australia.
- AS/NZS (Standards Australia and Standards New Zealand). 2011. *Structural design actions, Part 2: Wind actions*. AS/NZS 1170.2:2011, Sydney, Australia.
- ASRO (Association of Standardization in Romania). 2007. *Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. National Annex [Romanian]*. SR EN 1991-1-4:2006/NB:2007, Bucharest, Romania.
- AWG (Aruba Gobierno). 2013a. *Bouw- en woningverordening [Dutch]*. AB 1999 no. GT 9, Oranjestad, Aruba.
- AWG (Aruba Gobierno). 2013b. *Bouw- en woningbesluit [Dutch]*. AB 1999 no. GT 10, Oranjestad, Aruba.
- BAGL (Building and Construction Agency). 1995. *Regulations for Loads on Structures [Danish]*. Nuuk, Greenland.
- BAPE (Barbados Association of Professional Engineers). 1981. *Code of Practice for Wind Loads for Structural Design*. St. Michael, Barbados.
- BCA (Building and Construction Authority). 2019. *Approved Document - Acceptable Solutions*. Singapore.
- BD (Buildings Department). 2009. *Practice Notes for Authorized Persons, Registered Structural Engineers*

- and Registered Geotechnical Engineers. PNAP ADM-1, Hong Kong, China.
- BD (Buildings Department). 2019. *Code of Practice on Wind Effects in Hong Kong and Explanatory Notes*. Hong Kong, China.
- BDS (Bulgarian Standards Institute). 2011. *Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions - National annex to BDS EN 1991-1-4:2005 [Bulgarian]*. BDS EN 1991-1-4:2005/NA:2011, Sofia, Bulgaria.
- BEC (Board of Engineers Cambodia). 2016. "Technical Book." Accessed October 30, 2017. <http://pailin.cambodia.gov.kh/index.php/page/view/cid:28/pid:81/year:2016/month:March/lang:en>.
- Belize Building Act*. 2011. Chapter 131, Belmopan, Belize.
- BES Public Housing, Spatial Planning and Environmental Management Act [Dutch]*. 2011. Hague, Netherlands.
- BIS (Bureau of Indian Standards). 2005. *National Building Code of India*. New Delhi, India.
- BIS (Bureau of Indian Standards). 2007. *Code of Practice for Design Loads (other than earthquake) for Buildings and Structures - Part 3: Wind Loads*. IS 875 (Part 3):1987, New Delhi, India.
- BIS (Bureau of Indian Standards). 2015. *Code of Practice for Design Loads (other than earthquake) for Buildings and Structures - Part 3: Wind Loads*. IS 875 (Part 3):2015, New Delhi, India.
- BIS (Bureau of Indian Standards). 2016. *National Building Code of India*. New Delhi, India.
- BNSI (Barbados National Standards Institution). 2010. *Code of Practice for Wind Loads for Structural Design*. Final Draft, BNS/DPC 2010-001, St. Michael, Barbados.
- BNSI (Barbados National Standards Institution). 2013a. *Wind load for structural designs - Technical report*. BNS TR 28:2013, St. Michael, Barbados.
- BNSI (Barbados National Standards Institution). 2013b. *Barbados National Building Code*. BNS SP 1:Parts 1-18:2013, St. Michael, Barbados.
- BOBS (Botswana Bureau of Standards). 2014. *Basics of structural design and actions for buildings and Industrial structures - Part 3: Wind actions*. BOS 536-3:2014, Gaborone, Botswana.
- Boverket (National Board of Housing, Building and Planning). 2019. *Boverkets konstruktionsregler [Swedish]*. EKS 11, Karlskrona, Sweden.
- BSI (British Standards Institution). 1970. *Code of Basic data for the design of buildings - Chapter V: Loading - Part 2: Wind Loads*. BS CP 3: Chapter V-2, London, United Kingdom.
- BSI (British Standards Institution). 1972. *Code of Basic data for the design of buildings - Chapter V: Loading - Part 2: Wind Loads*. BS CP 3: Chapter V-2, London, United Kingdom.
- BSI (British Standards Institution). 1997. *Loading for buildings - Part 2. Code of practice for wind loads*. BS 6399 Part 2:1997, London, United Kingdom.
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