THE ROLE OF HOSPITAL MORPHOLOGY IN MANAGING WIND LOADS AND WIND-INDUCED BUILDING MOTION IN HEALTHCARE BUILDINGS

A Thesis Submitted to
The Graduate School of Engineering and Sciences of
Izmir Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in Architecture

by
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June 2024
İZMİR

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ACKNOWLEDGEMENT

I would like to thank everyone, my advisors, my professors, my family, and my friends, who helped and supported me in this study.

First of all, I would like to thank my advisor, Assoc. Prof. Dr. Altuğ Kasalı for his interest, understanding, sincerity, and help throughout my master's degree. I am grateful for the experiences and knowledge he shared.

Secondly, I would like to thank my co-advisor Asst. Prof. Dr. Uğur Demir for his guidance, enthusiasm, and support. The information and guidance he provided from the very beginning of the study were crucial for the accomplishment of this thesis.

Thirdly, I extend my heartfelt thanks to Prof. Dr. Mustafa Emre İlal for his unwavering support and patience. He generously answered all my questions during the programming process, and greatly broadened my horizons with his insightful lectures.

I would also like to thank my parents, my mom Gülden Özsu Koç and my dad Erdal Koç, for their endless support, love, and patience.

And last but not least, I would like to thank my sister Ayça Helin Koç for her friendship and cheerfulness. I wish her success and luck in her journey to become an architect.

ABSTRACT

THE ROLE OF HOSPITAL MORPHOLOGY IN MANAGING WIND LOADS AND WIND-INDUCED BUILDING MOTION IN HEALTHCARE BUILDINGS

This thesis investigates the relationship between wind loads and inpatient tower morphologies and the architectural ramifications of this interplay with a particular emphasis on the impact of wind-induced building motion on occupant comfort. The formation of inpatient floors and the roof selection play a decisive role in shaping these morphologies. This thesis seeks to understand the relationship between different morphologies and the change in wind effect and its implications. To establish a foundation for wind analysis, various floor typologies were scrutinized, and hypothetical floor plans were developed. Using calculations based on EN1991-1-4 and ASCE 7-22 standards, the study investigates the wind loads through various inpatient floor layouts. The buildings were analyzed based on six different factors: inpatient floor plan, building orientation, height, roof type, roof slope, and exposure category. The calculations performed reveal differences between the codes. The building motions due to these wind loads are compared with the comfort limits given in the literature to examine the effects of the differences in the obtained results. The findings reveal significant differences in wind load calculations between codes regarding wind speed, building height, and assumptions about environmental conditions. In the building motion-human comfort analysis made depending on these differences, it was revealed that these differences caused the comfort limits of the building to be exceeded at different floor levels. Therefore, the study emphasizes the critical role of evaluating building safety and human comfort related to wind-induced motion perception under wind loads, underscoring the necessity for a nuanced understanding of different standards.

Keywords: Healthcare Facilities, Hospital Morphology, Motion Perception, Wind Loads

ÖZET

SAĞLIK YAPILARINDA HASTANE MORFOLOJİSİNİN RÜZGAR YÜKLERİ VE RÜZGAR KAYNAKLI BİNA HAREKETLERİNİN YÖNETİMİNDEKİ ROLÜ

Bu çalışma, rüzgar yükleri ile yataklı tedavi ünitelerinin morfolojileri arasındaki ilişkiyi ve bu etkileşimin mimari sonuçlarını, özellikle rüzgar kaynaklı bina hareketlerinin konfor üzerindeki etkisini vurgulayarak araştırmaktadır. Yataklı tedavi katlarının tasarımındaki farklı yaklaşımlar ve çatı seçimi, bu morfolojilerin şekillenmesinde belirleyici bir rol oynamaktadır. Hastane yapılarında yataklı tedavi ünitelerinin mekânsal düzenlemesi ve tasarımı, operasyonel verimlilik, hasta memnuniyeti ve sağlık hizmeti sonuçları üzerinde önemli etkilere sahiptir. Bu çalışma, farklı morfolojiler ile rüzgar etkisindeki değişimler arasındaki ilişkiyi ve bunun yansımalarını anlamayı amaçlamaktadır. Rüzgar analizi için bir temel oluşturmak adına, çeşitli kat tipolojileri incelenmiş ve varsayımsal kat planları geliştirilmiştir. EN1991-1-4 (2005) ve ASCE 7-22 (2022) standartlarına dayanan hesaplamalar kullanılarak, çeşitli yataklı tedavi kat plan düzenlemeleri üzerinden yapıya etki eden rüzgar yükleri incelenmiştir. Bu amaçla, binalar altı farklı faktöre göre analiz edilmiştir: yatan hasta kat planı, rüzgar yönü, bina yüksekliği, çatı tipi, çatı eğimi ve rüzgar maruziyet kategorisi. Hesaplamalar, standartlar arasındaki çevresel varsayımlara dayalı farklılıkları ortaya koymaktadır. Rüzgar etkilerine bağlı bina hareketleri, konfor sınırları ile karşılaştırılmıştır. Rüzgar kuvveti arttıkça, farkların da orantılı olarak arttığı ve farklı kat seviyelerinde konfor sınırlarının aşıldığı gözlemlenmiştir. Bu nedenle, rüzgar yükleri altındaki bina hareketlerinin, bina güvenliği ve insan konforu açısından değerlendirilmesi kritik öneme sahiptir. Çalışma, farklı standartların birlikte anlaşılmasının gerekliliğini vurgulamaktadır. Bu araştırma, yapısal bütünlüğü ve kullanıcı konforunu artırmak için yatan hasta birimi tasarımı konusunda değerli bilgiler sunmaktadır.

Anahtar Kelimeler: Sağlık Tesisleri, Hastane Morfolojisi, Rüzgar Yükleri, Rüzgar Kaynaklı Yapı Hareketi

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GLOSSARY

Architectural Morphology (in hospital design): The arrangement and composition of spatial elements in hospital facilities, shaped by various medical, architectural, and social factors. (Mimari Morfoloji)

Aspect Ratio: The ratio of a building's height to its width or length. (En-Boy Oranı)

Building Motions: Movements or vibrations experienced by structures due to external forces, such as wind. (Bina Salınımı)

Commercial Building: A structure intended for commercial purposes, such as offices, retail spaces, or hotels. (Ticari Bina)

Exposure Categories: Classifications based on the level of exposure to environmental factors, such as wind, for various locations. (Maruziyet Kategorileri)

Human comfort levels: The degree of comfort experienced by occupants within a building, considering factors such as temperature, vibration, air quality, and noise. (İnsan Konfor Seviyeleri)

Inpatient units: Areas within healthcare facilities where patients are admitted for overnight stay or longer durations for medical treatment and care. (Yataklı Tedavi Birimleri)

Main Force-Resisting System (MFRS): Structural system designed to withstand primary forces like wind and seismic loads, ensuring building stability. (Ana Kuvvet Direnç Sistemi)

Peak Velocity Pressure: The maximum pressure exerted by wind on a structure. (Tepe Hız Basıncı)

Root Mean Square (RMS) Acceleration A measure of the overall level of varying acceleration, combining different components into a single value. It is crucial for assessing wind-induced vibrations on building comfort and safety. (Karekök Ortalama İvme).

CHAPTER 1

INTRODUCTION

1.1. Framing the Problem

Hospital facilities, as one of the primary building types, have been a topic of interdisciplinary research within various fields, including architecture, engineering, and operations research (Ulrich et al. 2004; Haq and Luo 2012; Jacob et al. 2013; Kasali et al. 2013; Price and Lu 2013; Johanes and Atmodiwirjo 2015; Nikfar and Konstantinidis 2019; Lee et al. 2020; Li et al. 2020; Pilosof 2021; Pouyan et al. 2021; Yuan et al. 2022). Beyond emerging challenges and complexities in contemporary healthcare design practice, the primary concern in hospital design involves creating a seamless flow of patients, staff, visitors, and equipment (Halawa et al. 2020). Various information and research emerging from different domains of inquiry inform the morphology of healthcare facilities, embodying the traces and effects of this flow. Therefore, every advancement -medical, architectural, or social- influences and shapes the program components and, eventually, the morphology of hospital buildings. With so many factors and stakeholders involved in the design of hospitals, morphology represents itself as a complex phenomenon.

In the scope of this thesis, the term "morphology" pertains primarily to the arrangement of spatial elements and the composition of masses in the design of hospital facilities. Steadman, with a particular focus on layouts, defines 'architectural morphology' or 'configurational studies' in architecture as a field that focuses on the limitations imposed by geometry on building shape and plan configurations (Steadman 1983). In hospital design, these limitations can be imposed on layouts and overall masses of buildings through multiple factors. Upon examining the notion of morphology concerning hospital architecture, it becomes evident that a significant amount of knowledge production has been attained in this particular domain. Therefore, the production of knowledge on obtaining the proper hospital form has led to different layout organizations and the use of different mass compositions over time (Forty 2003). The observed changes in forms are no longer seen as a phenomenon solely attributed to medical developments or technological improvements, but rather, they are the product of a combination and interplay of more complex cases (Kisacky 2017).

Therefore, to handle this complexity, the thesis followed a categorization of knowledge regarding hospital morphology to clarify how it is positioned within this complex web of factors. The categorization includes two main headings, intrinsic and extrinsic, with sub-headings that further specify and narrow down the categories. Some concepts were found to overlap during the categorization process, making their boundaries ambiguous. This was not seen as a disruption but rather as an indication of the interdisciplinary nature of the field and the need for a versatile approach. Although many categorizations can be made on a complex subject, such as hospital morphology, this thesis aims to emphasize the breadth of the subject and its ability to be examined across multiple domains.

Creating layouts for healthcare facilities is an interdisciplinary design problem that can be analyzed on two levels: intrinsic and extrinsic. Intrinsic parameters refer to factors that directly affect the functioning and behavior and associated outcomes of the plan, whereas the extrinsic parameters mainly pinpoint the relationship between hospital morphology and external factors. The research on intrinsic parameters involve the examination of the environment created within the hospital in terms of issues such as the healing process of patients (Park et al. 2018; Schweitzer et al. 2004; Ulrich 1984), medical knowledge (Prior 1988), staff and patient satisfaction (Garman et al. 2002; Li et al. 2015; Naidu 2009), wayfinding (Martins et al. 2014; Ndhlovu Rooke 2012), the workflow (Emanuele and Koetter 2007; Weigl et al. 2011), and relations between departments (Arnolds and Nickel 2015; Cubukcuoglu et al. 2022). Additionally, extrinsic parameters pertain to elements that influence the structure based on external factors. The external factors encompass the identities of the healthcare provider and receiver, the preferred architectural style, the city's silhouette, external dynamic forces, extreme conditions, and the social dynamics of communities. Therefore, researchers are developing an improved comprehension of the relationship between these parameters and hospital morphology.

Throughout history, researchers from various fields have proposed different viewpoints on how hospitals can enhance their efficiency and how the morphology of hospitals should be. In 1863, in the book *Notes on Hospitals*, Florence Nightingale drew attention to the relationship between patient recovery time and rate and the sanitation conditions on patient floors. She proposed a hospital morphology that would allow airflow, natural light, and landscape view to provide patients with better care (Nightingale 1863). Considering different parameters, this new approach resulted in a new generation of facilities characterized as the pavilion plan type (Risse 1999). With similar concerns relating to safety, efficiency, and flow, other different layout types eventually emerged, such as “double loaded corridor” or “racetrack” (Cai et al. 2012). Each proposed a varied layout configuration that aims to address issues arising from previous morphologies. These problems may be a) flow-related issues experienced using previous types, b) not meeting the space requirements arising from new technological developments, c) inability to meet the requirements of new medical and care procedures. These problems have presented themselves as new objectives that need to be achieved. Research-based approaches, including Evidence based design (EBD), have provided new insights into the ability of each type of plan to achieve these desired objectives. Consequently, the overall morphology of healthcare facilities, and the formation of inpatient floor has been studied extensively (Pachilova and Sailer 2015).

In addition, hospital inpatient floors, especially where nurses are actively involved, occupy a large share of the total hospital space. In light of this, one crucial aspect that determines the morphology of hospitals today is the inpatient unit floors. These floors typically include independent patient rooms, patient wards, nurse stations, and medication rooms. Depending on how the nursing units are positioned within the hospital inpatient floors, the functioning of these floors changes. Nurse stations show themselves as one of the main factors that create the hospital's workflow and culture (Zborowsky et al. 2010). In this manner, the literature suggests different configurations of inpatient unit layouts including single corridor, racetrack, compact circle, cross shape, Compact Square, and compact triangle (Kobus et al. 2008). Each layout indicates a different cultural setting within the hospital, and each has its advantages and disadvantages that will be further argued in the next chapters.

Evidently, the intrinsic parameters directly influence the functioning and results of the plan and are one of the main elements that constitute the hospital morphology. These factors, which directly affect the efficiency of hospitals, the healing process of patients, and the workflow of employees, are based on research that is taken into account in hospital design. Accordingly, it constitutes the majority of the knowledge produced in this field. Therefore, when evaluating the factors that affect the design and layout of hospitals, it is essential to consider the information available on the impact of architecture and environment on patients and their health outcomes.

The second set of concerns that shape the form of hospital facilities is the extrinsic parameters, which cover the influences beyond behavioral and care-related factors. It covers issues such as health providers' identity and community relations. This relationship shapes the services and practices provided in health facilities and can lead to changes in the culture within the hospital. Variables such as whether the church or the military provides care, to whom health care is provided, whether it is for the poor or the rich, and when care is needed during a war or pandemic affect the construction and the functioning; therefore, its morphology. This set of concerns includes these relationships, as well as the influence of period architectural styles, the building's relationship with the city skyline, and its response to external dynamic forces and extreme conditions. Thus, this category is analyzed through social, environmental, and structural dimensions.

The social dimension involves the factors that depend on the hospital's transformational relationship between healthcare and society, encompassing appropriate and commonly accepted preferences. The social status and preferences of doctors, patients, nurses, and architects show themselves as factors that affect the morphology of hospitals. In addition to these factors, architects' preferences and contemporary trends were among the determining factors (Forty 2003). Apart from the preferences of healthcare providers and designers, the preferences of the users of hospital buildings are also factors affecting the morphology. It has been observed throughout history that as these preferences change, the social functions attributed to hospital buildings and, therefore, the morphologies of hospitals change accordingly. The use of hospitals for medical education and the superficial resemblance of these buildings to different building types depending on architectural preferences -such as the resemblance to office buildings after industrialization and Palladian buildings in the eighteenth century (Forty 2003) can be examples of such transformations.

The environmental dimension, on the other hand, concerns the relationship between physical environmental factors and hospital morphology. These physical factors refer to the location of the hospital in the region, the defining characteristics of this region, the conditions under which and how access to the hospital is provided, the terrain conditions, and thus the relationship between these and the morphology. The relationship shared by a hospital with its surroundings plays a pivotal role in determining the entrance and exit points of the facility. This, in turn, influences several fundamental principles that shape the overall morphology of the hospital.

The structural dimension involves key parameters pertaining to features that impact the hospital morphology. Like any other building, structural advancements change the morphology of hospitals. In the early 1900s, the opinions on how the circulation between different hospital units in pavilion type decreased the efficiency of hospitals triggered the shift to high-rise hospital structures (Kisacky 2017). This shift changed the formation of hospital structures and solved the problem of finding a large parcel in the urban area. Apart from the rise in the number of floors, the healthcare facilities have also grown in volume to meet new health requirements, and their complexity has increased. Kim categorizes this complexity as functional complexity, technological complexity, scientific knowledge complexity, aesthetic complexity, and interest group complexity and draws attention to the effect of this complexity on design culture (Kim and Shepley 2011). Furthermore, according to Latimer et al.'s research (2008), where he examines the growth of hospital units within the last 28 years, the factors influencing this growth can be listed as a) change from communal to individual patient rooms, b) the creation of spaces for the patient accompanist in rooms, c) including patient toilets and showers in the rooms, d) new regulations, e) consumer expectations and market competition (Latimer et al. 2008). Moreover, due to hospitals' large and higher structure, their place within the city silhouette changed accordingly, remarking them as Lynch's definition, "landmarks" (Lynch 1964). Evidently, this growth increased the structural complexity and underscored the matter as a crucial subject that requires further investigation.

Another aspect of how external factors influences shape hospital morphology is how these structures respond to unusual or changeable parameters. Another reason why these loading conditions present additional importance in healthcare facilities is that healthcare facilities must be able to bear up to extreme weather conditions and maintain their structural and operational integrity to ensure the safety of patients, staff, and visitors (Bar-Dayan et al. 2000; Chand and Loosemore 2015; Ceferino et al. 2020). These changeable parameters for structures dynamic loads including but not limited to wind loads, earthquake loads, blast loads, and human-induced vibrations (Kappos 2002). Regarding hospital buildings, codes and restrictions are established primarily for fire and earthquake situations. Design decisions made to meet these regulations and rules appear as phenomena that influences the shape of hospital morphology (Guerrero et al. 2022). Accordingly, these regulations, which cannot be ignored when making design decisions, should also be among the factors affecting morphology.

The connection between morphology and wind conditions can be characterized as more ambiguous and blurred. The effect of wind on hospital morphology is a more interconnected phenomenon. The set of architectural decisions such as layout plans, facade design, building geometry, roof type, context, corner modifications, and building orientation are determinants for wind exposure (Davenport 1971; Hoxey et al. 1993; Kwok 1998; Merrick and Bitsuamlak 2009; Nagar et al. 2020). In the case of hospital buildings, wind pressures can have significant consequences, as these structures often have many windows, higher walls, and other features that can make them vulnerable to wind damage. The inefficient choice of shape can lead to higher construction costs for buildings in case the wind exposure is not taken into account carefully. Like most manufactured buildings, hospital structures are bluff body objects in wind dynamics studies. These bluff body structures can be in cylindric and rectangular forms. Air flowing around and over these bluff bodies usually creates turbulent wake zones behind them. According to Irwin (2008), the suction areas, side, and rear facades of the buildings relative to the wind direction where wind exposure create suction forces, created by these bluff body structures can quickly increase to levels that adversely affect human comfort (Irwin 2008). These bluff body buildings mostly face the most critical wind pressure on their windward elevations. However, observing these critical wind pressures on other faces for irregular-plan-shaped buildings with plan layouts of T, L, Z, +, Y, E, and other variations is possible. Furthermore, regardless of the shape of the building, the opening locations represent themselves as critical elements that affect the internal wind pressures (Woods and Blackmore 1995). The size and locations of the openings on building facades cause the aforementioned internal pressures. Depending on their proportions on the facades, these openings generate inward wind pressures when situated perpendicular to the wind, and outward or suction pressures when positioned on the facade opposite or parallel to the wind direction.

There is a variety of factors that influence the hospital's morphology. The discernible impact of specific factors has been comparatively more conspicuous and subject to greater scrutiny than others (Ulrich et al. 2008). Apart from these well-studied factors, other factors that considerably affect the formation of hospital morphology have been relatively less studied. This thesis focuses on one of the extrinsic factors, namely wind effects, whose relationship with hospital typology has been relatively less studied. In this context, the effect of wind exposure on different hospital morphologies will be analyzed through current international guidelines.

There are numerous methods and country-specific calculation codes to determine the effects of wind on structures. This thesis will consider two major guiding documents, namely the EN1991-1-4 (2005) and ASCE 7 (2022) (Hereafter EN1991-1 and ASCE 7-22, respectively) as significant standards for analysis and evaluation. Although the wind load calculation strategies proposed by EN1991-1 and ASCE 7-22 are comparable, there are variations in coefficients, formulations, and environmental considerations. These variations increase the likelihood of ambiguity between ASCE 7-22 and EN1991-1 regulations. Moreover, ASCE 7-22 contains information on different wind calculation procedures. ASCE 7-22 calculates the wind effects on the structure of two systems. For these two different systems, the two systems in ASCE 7-22 are the main force-resisting system (MFRS) and component and cladding. In addition, it examines and presents MFRS in two procedures: directional and envelope. In the scope of this study, the procedure used is the directionality procedure.

In addition to this, the calculations mentioned in both codes and some pre-calculated tables present in ASCE 7-22 are only for square and rectangular shape variations. Therefore, the existing codes and standards need to contain more data to adequately examine the complex building shapes (Hoxey 1993). As mentioned above, numerous research studies are available on wind exposure on buildings with irregular plan layouts. However, both codes above recommend wind tunnel tests for irregular-shaped buildings that are not calculable by the simplified formulas. When designing more complex structures, for instance, healthcare facilities, these documents guide the designer in conducting a wind tunnel experiment. Practicing intricate simulations for each design concept or running a wind tunnel experiment can be time-consuming and costly. Therefore, it seems necessary to comprehend the predictable reactions to wind exposure in stereotypical forms.

Griffis (1993) examines the effect of wind exposure on buildings in two dimensions: deformation and motion perception. The effects expressed by deformation usually refer to damage to non-structural elements, such as wind-induced damage to roofing or wall cladding. Secondly, motion perception is related to the impact of wind-induced vibrations on human comfort. When the effect of building movements on people is analyzed, many factors affect this relationship, such as sex, age, body posture, body orientation, body movement, the expectancy of motion, visual cues, acoustic cues, and type of motion. People are known not to be highly sensitive when an object is moving at a constant velocity. However, acceleration necessitates a force, which can trigger sensations in different organs and senses in the body (Griffis 1993). Therefore, peak and root mean square (RMS) acceleration are widely used to evaluate human perception of wind-induced building motions.

Although it is essential to take the measures required by both criteria, the evaluation of motion perception on human comfort is a more subjective assessment in comparison to deformation caused by wind forces (Kwok 2013). The effect of wind-induced vibrations in hospital structures affects not only the comfort of patients and the working efficiency of staff but also the medical instruments, equipment and imaging technologies used in daily routine operations.

As previously mentioned, the organization of layouts and masses of healthcare facilities isn't defined by a single factor but by various factors. Therefore, hospital morphology is an interdisciplinary issue that requires multidimensional research. To efficiently address this issue, designers and design teams with diverse educational backgrounds should be able to obtain information from various fields. In this context, this thesis aims to examine the effect of wind exposure on design decisions and hospital morphology with an interdisciplinary approach.

1.2. Research Aim and Objectives

This thesis aims to reveal the impact of architectural decisions on severity of wind pressures as well as resultant motion perception of the occupants within the context of human comfort, emphasizing the significance of designing hospital inpatient floors. It investigates this link between the design decisions and the loads affecting the healthcare structures and examines to what extent this link should play an active role in the design process.

In addition to the primary purpose, the study also aims to draw attention to the necessity of interdisciplinary knowledge to guide the design of healthcare facilities.

Altogether, the objectives of this thesis can be listed as follows:

1) To determine the impact of architectural design decisions taken during the selection of morphology on wind-induced response of hospital buildings

2) To clarify the major differences between the boundary conditions of explored wind calculation approaches and tabulated codes on wind response of healthcare facilities
3) To shed light on the impact of variations of architectural form, wind exposure, motion perception and related human comfort, on design of hospital buildings

To achieve the stated objectives, the research uses hypothetical calculations and data analysis methods to determine the extent of the impact caused by the layout choice for wind exposure. Specific research questions were formulated to address these issues and guide the research process. This process will begin with understanding the relationship between wind exposure and morphology, layout choices, and facade design. Then, later, continue with a more specific concept, the differences suggested by diverse methods. To accomplish this, a calculation algorithm that considers two different documents to examine the degree of differences between the variations suggested by the different documents used by various countries was created (Figure 1.1, 18).

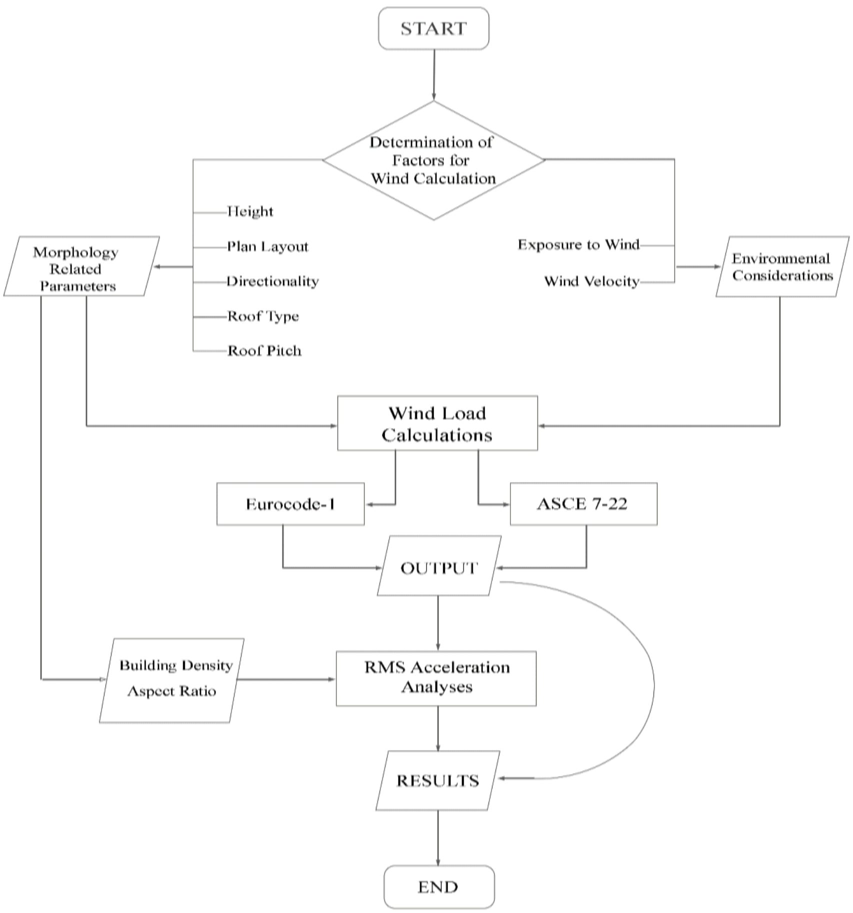


Figure 1.1. Data Flowchart

1.3. Research Questions

Numerous factors influence the morphology of buildings, including a variety of factors, wind exposure being one of them. But, to what extent does the shape of the healthcare facility affect the wind exposure? This thesis addresses the question by employing calculations based on existing wind load standards to evaluate various morphological design choices. That will try to designate in which situations, which inpatient unit layout and hospital morphology provide the user and constructer with more advantages.

Therefore, the main question of the study and its sub-questions can be formulated as follows:

1) What is the interconnected relation between the morphology of hospital buildings and wind exposure?
2) What morphological features of hospital layouts are critical concerning the wind exposure?
3) To what extent are the differences between different wind load calculation codes, what are the reasons behind these differences, and to what extent do they affect working groups involving different stakeholders?
4) Can preliminary wind calculations yield a criterion in selection of roof type during design phase? What is the relationship among form, wind pressure and roof type?
5) How does hospital morphology and wind exposure interaction affect the motion perception? What are the given limits? In which cases these limits are exceeded?

1.4. Research Method and Thesis Outline

The thesis employs quantitative methods to pursue the research questions. A literature review is presented to identify the formation of hospital structures, the spatial organization of hospital inpatient care units, and the factors that influence the establishment of plan layouts and morphologies. In light of the information gathered from this literature review, three frequently repeating layout types were identified for further study. Each type represents a different nurse unit configuration within the inpatient care units. These identified hospital types have created a base as hypothetical buildings to use in the calculations.

After establishing the foundation for the calculations, a review of the two wind calculation methods, ASCE 7-22 (directionality procedure for main force-resisting systems) and EN1991-1, was conducted. The formulas and coefficients used in both methods were compared. Intending to analyze a broader range of examples, the authors developed a JavaScript program that calculates the wind exposure acting on buildings for both codes. In addition to the mentioned calculations, building motions were analyzed for each building model based on the data at hand. The results were compared with the motion perception limit values found in the literature. The results of the calculations were then evaluated concerning the different dimensions of the hospital morphology problem, which were the result of the literature review. Subsequent to conducting a thorough analysis, pertinent observations were articulated, and decisive inferences were deduced.

This thesis is formulated in six chapters, each dealing with a different part of the methodology given above. In Chapter 2, the study presents the literature review in two phases. The first phase provides the necessary background information to analyze commonly used inpatient floor types. Examines the historical development of hospital buildings and the efforts made to improve their design. The hypothetical types created with the information gathered from this literature review are presented in the following Chapter. In the second phase, the Chapter provides information on motion perception and human comfort criteria regarding motion perception, creating a basis for evaluating the results. Chapter 3 presents the building types, building matrix, and calculation methods. Chapter 4 presents the results of wind load calculations and root mean square acceleration. In Chapter 5, the results are discussed from a multidisciplinary perspective on four levels: the effect of size, the impact of code differences, roof pressures, and roof selection, suitability of building motion limits to healthcare facilities. Chapter 6 summarizes and presents the results and main findings from the literature review and calculations.

CHAPTER 2

BACKGROUND

This chapter serves as a literature review designed to lay the groundwork for subsequent discussions and to scrutinize the range of limit values and diverse perspectives. It aims to provide a comprehensive background for two significant issues at hand. Firstly, the section delves into the impact of hospital plans and morphology configuration on patients and employees, as documented in the literature. Secondly, it explores the influence of building movement related to wind exposure on human well-being and comfort.

2.1. Hospital Morphology and User Experience

Healthcare facilities show themselves as one of the spaces with the most diverse opinions on their ideal form. Due to this diversity of ideas, the morphology of hospitals has changed many times over the last 200 years. However, according to Forty (2003), the main purpose of these ideas was not to change the hospital morphology, but rather to provide innovative perspectives to improve patient care (Forty 2003). Therefore, the change of form was a tool and not the aim. Furthermore, the presented perspectives were shaped by a multitude of determinants, including, but not limited to, the swift evolutions and prevailing trends in patient care, as well as societal dynamics and behavioral patterns (Haron et al. 2012). Therefore, it is necessary to understand the historical development of these forms to analyze the reasons for the changes in the hospital form, how form influences the users of these spaces, and the inputs that will form the future forms. A significant amount of research has been produced on how the form of a hospital influences user interactions, the operation of these spaces and the user's satisfaction (Lu et al. 2009; Heo et al. 2009; Cai and Zimring 2012; Koch and Steen 2012; Pachilova et al. 2013). Furthermore, according to Haron (2012), user satisfaction stands out as a criterion for understanding the design success of the hospitals. Consequently, this chapter is devoted to a comprehensive presentation and analysis of these matters in greater depth.

2.1.1. Evolution of Hospital Morphology

Over the years, the spaces where patient care takes place have changed due to medical opinions, the technologies used in patient care, and new research in evidence-based healthcare facility design. These spaces evolved from homes to religious facilities and, in time, to hospitals. Nonetheless, the foundations of the buildings defined as hospitals today are where health services were first provided, namely places of worship. Over the years, numerous key events have influenced the mass typology and plan layout of the spaces that provide care for the sick and injured.

In ancient times, religion and medicine were strictly bound together. Patient care was mostly provided by religious authorities within religious buildings. In ancient Egypt, health-related practices resembled magical rituals. These healing rituals often took place in temples, which were massive stone structures that were supported by columns (Tesler 2018). Similarly, in ancient Greece, the act of healing took place in Asclepius which were temples devoted to the god of medicine Asclepius. They served both those who seek medical and spiritual healing (Risse 1999). Therefore, the characteristics of hospitals resembled religious buildings. In the early Middle Ages, attention to the sick was also mostly provided by the religious authorities. The facilities were in the form of hospice, or more like a shelter for the ones in need rather than today's hospitals. The medical care was given mostly by the sisters or lay nurses (Tesler 2018). Before the 16th century hospitals showed little care for patient comfort or hygiene (Miller 1985). Nonetheless, they cared for the spiritual healing of the patients due to their religious identity (Abreu and Sheard 2013). During that era, hospitals were constructed with distinct layouts compared to modern-day facilities. This was largely influenced by the social hierarchy of the time and the entities responsible for administering healthcare. Upon further examination of the environmental factors, it is evident that the living conditions and the requirement for hospital infrastructure were closely intertwined with the populace's health. Therefore, by the Middle Ages, underdeveloped rural settlements and crowded medieval towns became the source of diseases (Currie 2007).

Afterwards, in the 19th century, Florance Nightingale had established a connection between the sanitation of the patient environment and patient survival rate. She proposed spaces that provide the patients with a good amount of natural light, fresh air, a view of the landscape, clean and sanitary environment (Nightingale 1863). Her ideas pioneered the design of St. Thomas's Hospital in London which was built between 1861 and 1865. The design was an example of a pavilion-type, and an implementation of Nightingale's view on efficient circulation and humanistic principles. The first pavilion hospitals to be built were Stonehouse (1821-1829), Beaujon (1837-1844) and Lariboisière (1846-1854), but none of them were exceptionally successful in reducing mortality (Forty 2003). However, the pavilion-style hospital became very influential. Pavilion-type hospital masses have strong and still accepted medical views behind them. The pavilion-type hospital buildings contain more than one building mass. The reason why these masses are separated from each other is to prevent the spread of diseases and to enhance the natural light and air. The masses are mostly connected by closed circulation spaces. Pavilion-type hospitals include a linear spine that connects the whole facility. The gaps between departments in this type of hospital structure have also contributed to the increase in the relationship of patients with green and nature (Verderber and Fine 2000). These types of hospitals are low-rise and sit on a wide base.

In the Nightingale or Open ward, the ideas put forward by the nightingale such as air circulation, the need for natural light, and providing the patient's visual communication with the garden and outside were adopted. In this type of ward, patients are treated in the same place without separating surfaces. For these types of wards, the optimal sizes were determined by the patient number which was 20 to 30 in the mid-19th century. These numbers constituted so that all patients were within the nurses' field of view. According to Thompson and Goldin, the openings were approximately 1 in third of the entire wall (Thompson et al. 1975). The windows were placed between patient beds (Cai 2013).

In the 18th century, specialized hospitals were established, and semi-specialization emerged. According to Currie (2007), hospitals in the 18th century were different from their previous examples in three ways. Firstly, the hospital became teaching centers as well as treatment centers, they offered teaching programs. Thus, the number of trained doctors became more than ever before. The amphitheater operating rooms were used. They gave students to observe surgical operations. These rooms were in the form of a circular amphitheater which had the operating table in the middle. Secondly, there were more outpatients than inpatients. Which resulted in changes in the hospital space requirements. And lastly, specialized hospitals began to split from general hospitals. In consequence, the application and development of new treatment methods was triggered. Women's and children's hospitals began to be built and used more (Currie 2007). As hospitals were separated according to their specialization, spaces began to be shaped based on their needs, and different spatial connections and functioning cultures began to be encountered.

The developments in technology and medicine in the modern era stated different space requirements for hospitals. The invention of Xray in 1985, the development of penicillin in 1897, and the first modern operating room in 1897 changed the already existing hospital spaces or added new spaces to the requirement list. With the invention of the elevator, moving the patients vertically became a tempting option to create higher hospital buildings. The overpopulation in the cities and fast urbanization caused the land value to rise. Designing hospitals big enough to accommodate all these people became the ultimate challenge. In this sense, the hospitals' form started to change from a pavilion to a "podium on a platform" type. As these towers rose, the patients' relationship with nature began to break. Nightingale's teachings about patient psychology, and connection with landscape began to be forgotten, and hospitals began to be designed as machines.

After the structural advancements in 1921, E.F. Stevens proposed a new plan type that suggested the spaces were placed on top of each other rather than next to each other. This improvement was possible through the invention of the elevator. The first multistory hospital buildings were built in 1929 in Los Angeles and 1932 in New York. This paradigm shift also changed the positioning of hospital buildings in the city silhouette (Tercan 2012). This type of hospital is referenced as a high-rise hospital building. The height of the building directly affects the wind loads on structures. With this alteration, the importance of wind becomes more crucial. The block-type hospital buildings are mainly formed as L, T, H, or Y. Each shape responds to the wind in different ways. When the shape has more indentations, wind generates different pressure zones on the corners. Correspondingly, the cost of the building gets higher. With the improvements of building technologies, it has become possible to make buildings higher, this need comes from the rapid urbanization and overpopulation in the cities. A facility that can meet the needs of such a high number of patients in the form of a pavilion style would take up an incredible amount of space. This wouldn't be sufficient considering the value of the land in an urban environment. Accordingly, the morphology of inpatient facilities, which are the high-rise parts of hospital buildings, started to acquire importance. These morphological types, which continue from different solutions in plan types, have changed over time with the effect of different patient care approaches.

One of the proposals developed in addition to the floor form with patient beds proposed by Nightingale, the single corridor plan is patient rooms positioned on both sides of the central circulation spine. On one side of this central circulation, or corridor, is located a nursing unit, mostly placed in the center of the length of the ward to increase patient visibility and to decrease the walking distance of nurses. It can be in the shape of a rectangular, L-formed single spine. Similar to the open ward, the single corridor plan also consists of 20-30 patient beds (Cai 2013).

Subsequently, the proposed, the Racetrack, also known as the double corridor plan, was developed after the technological improvements in air conditioning. This plan type consists of a nursing unit area in the center of the ward with circulation spaces. According to Kliment, this plan type is more efficient than a single corridor plan. Even though the plan works efficiently during the daytime, the patient rooms at the ends of the corridors aren't getting enough attention during the nights when the hospital staff is limited (Kobus et al. 2008). Besides its advantage of efficiency, it has high building costs (Kazanasmaz 2005).

Furthermore, the courtyard plan alternates the racetrack plan by adding a courtyard to the central part of the plan to provide necessary light and ventilation to nurse stations and service spaces. In this plan type, the floor area of the hospital gets wider. While the patient rooms are located on the outer perimeter, the service areas are located around the courtyards. In this plan typology, the walking distance for nurses increases, which, according to Cai (2013), results in a sacrifice in the efficiency of hospital staff. These courtyards can be used for multiple purposes. Besides lighting and air conditioning, they are used as playgrounds, gardens, and healing. Although they do not have exact dimensions and shapes in hospital buildings, they are most seen in the form of squares and rectangles surrounded on four sides (Almhafdy et al. 2013).

Over time, the height, shape, and morphology of hospital buildings have changed depending on patient care approaches, developments in building technologies and medical research. One of the most critical reasons triggering these changes and developments is the research on patient and employee satisfaction in healthcare facilities.

The following sections will conclude these studies under two headings: patient satisfaction and their impact on the healing process and staff efficiency and workflow.

2.1.2. Impact of Layout on Patient Satisfaction and Well-Being

Recent research has shown that the configuration of hospitals changes the movement of users, the visibility of patients, physician-nurse, patient-physician, and nurse-patient communication, affecting the functioning of the hospital as well as patient outcome and satisfaction (Lu et al. 2009, Heo et al. 2009, Cai and Zimring 2012; Koch and Steen 2012). In this sense, these concepts constitute an important basis for measuring the effectiveness of hospital plan layouts. In further elaboration, as mentioned by Ulrich (2008), analyzing the impact of a variable in healthcare settings is challenging. The difficulty in carrying out controlled experiments within hospital environments makes it hard to accurately determine the true influence of a variable. This complexity arises because any alteration to one element can have effects on other variables, thereby complicating the assessment process (Ulrich 2008). In this manner, the information provided from the EBD research may improve the patient and staff outcomes (Pachilova 2013).

Pascoe defines patient satisfaction as, a health service recipient's response to important elements of the service experience (Pascoe 1983). According to Cleary and McNeil (1988), a patient's satisfaction includes a cognitive process and an emotional reaction to the surrounding environment and the services provided (Cleary and McNeil 1988). Moreover, healthcare facilities accommodate various user groups. For these user groups, the atmosphere fostered by the hospital and its conveyed significance differs, regarding their sociodemographic characteristics, leading to varying space-related expectations among these groups (Cifter and Cifter 2017). In further discussion, the patients' perception of space and healthcare services varies depending on their cultural and social background (Mourshed and Zhao 2013). According to Manary and Zhao (2013) to avoid inconsistence outcomes in patient satisfaction research there are some points to consider. Therefore, the researchers should focus on a specific event or visit, and patient-health provider interaction. In addition to this, Manary highlights the time relationship between the surveys and the provided service. In this sense, he underlines that the surveys should have been conducted up to 42 days after the service procurement (Manary et al. 2013).

Furthermore, according to Cleary and McNeil (1988), patient satisfaction is an indicator of quality of care because one key element in providing a good care is the patient communication and involvement. According to Pachilova (2013), the interaction between patient and caregiver constitutes the most significant activity in healthcare facilities. However, the time spent on this activity may change related to the spaces provided for staff to interact with one another. It is observed that the coefficient of importance of interaction with the patient increases in cases where employees in the hospital communicate with each other more frequently. On the contrary, where this interaction decreases the importance of communicating with other staff and patients are more equivalent to each other (Pachilova 2013). The distance between the places where this communication is provided to the areas where the patients are located also changes the patient's perception of the care they receive. Patients' satisfaction varies depending on their distance from the nurse stations. In MacAllister's study (2018), authors observed the highest satisfaction in the rooms defined as medium distance from the nurse stations. The reason for this is that the patients in the rooms close to the nurse stations are disturbed by the constant noise and movement, whereas the patients in the rooms at a distance defined as long think that they cannot communicate with the nurses sufficiently (MacAllister et al. 2018). Likewise, patients who have a clear line of sight are better supervised (Hendrich et al. 2002). In addition, Hall (2003) found that patients who stayed in rooms located further away from the doctor's workstations had to wait longer to access medical services.

There is a growing body of research that argue the distance of hospital rooms from nurses' stations not only affects patient satisfaction but also the immortality rate of patients. According to these studies, the distance of patients from nurses' rooms affects not only their communication between patients and staff but also the nurse's ability to observe patients full-time and visibility. Relatively, nurses' reaction time to patients' abnormal behaviors is shortened in rooms with high visibility (Leaf et al. 2010; Lu et al. 2014). This closely affects patient immortality rates and satisfaction.

Other than the communication and accessibility to the staff, hospital layout has been also argued to effect patient falls. Therefore, effective design of can also contribute to reducing patient falls by including proper room layouts and increasing the visibility of patients to nurses. Patient falls can occur from various of reasons such as physical, psychological reasons (Gulwadi and Calkins 2008), reasons due to the way nurses operate within the hospital, centralized or decentralized nurse stations (Brewer et al. 2018), assistive devices (Hitcho et al. 2004) and bed rails (Grasso et al. 2001).

Hospital design principles can also improve patient outcomes by influencing patients' psychology. The relationship between hospital buildings and their surroundings is also an output of design decisions and morphology. In this sense, the ties that hospitals establish with green, nature and outdoor spaces are also included in the design decisions. According to studies, it has been observed that these connections have an impact on patient recovery times, patient satisfaction levels and psychology (Ulrich 1984; Twohig-Bennett and Jones 2018; Jiminez et al. 2021). In his 1984 study, Ulrich examines the effect of views of hospital rooms on patient recovery processes. In this context, he examines the nurse's notes, pain medication given to the patients, stress and anxiety levels of the patients, and discharge times of the patients in two different room types located in the same corridor, having the same physical characteristics such as height and openness, but one facing a tree area and the other facing a brick wall. As a result of his study, he observed shorter discharge times, less pain medication, lower post-surgical complications in patients who stayed in the room facing the area with deciduous tree. in addition, although he observed the same stress levels in patients staying in both room types, he argues that this was due to the fact that the patients stay in the rooms with the view of brick wall were given more analgesic doses (Ulrich 1984).

In conclusion, hospital morphology and layout affect patients' satisfaction and well-being in many different ways. The magnitude of these impacts is contingent upon the underlying causes for patient hospitalization, in addition to their age, gender, and demographic characteristics.

2.1.3. Impact of Layout on Staff Efficiency and Workflow

Numerous studies have demonstrated a connection between the layout of buildings and various organizational behaviors, such as movement, physical proximity, mutual awareness, and spontaneous social interactions (Grajewski 1993; Serrato and Wineman 1999; Penn et al. 1999; M Rashid and Zimring 2003; Rashid et al. 2006;

Peponis et al. 2007; Sailer and Penn 2007; Sailer et al. 2009). These studies highlight how crucial layout characteristics like visibility and access are for encouraging intentional movement, direct communication, mutual awareness, and overall organizational effectiveness. Furthermore, a large number of studies have been carried out to provide designers with information on which of the Inpatient Unit Layouts is more efficient (Freeman 1967; Sendler 1968; Trites et al. 1969; Thompson and Goldin 1975). Various studies have used different evaluation criteria, such as nurses' walking distances, visibility assessment, staff interaction, and so on, to identify the types of plans that they defined as relatively more effective.

According to Donchin et al. (1995), verbal miscommunications between physicians and nurses are responsible for 37% of errors in inpatient wards. Consequently, the communication dynamics within inpatient unit floors are critical components that could be significantly improved through the adoption of an appropriate layout. In this context, workstations in inpatient units play an active role in shaping this communication (Penn and Hillier 1992). According to Peponis (2007), as a result of movements and visual communication in work environments, employees gain increased awareness of their colleagues' professional activities. Furthermore, in environments where there is high visibility, nurses are faster to recognize incidents, and consequently, response time is shorter (Harvey and Pati 2012; Apple 2014; Lu and Wang 2014; Pati et al. 2016).

Moreover, the location of certain functions within the plan types is also one of the factors that shape workflow and interaction. According to Sailer’s (2007) attraction model. Certain functions spaces the flow of the space regarding their utility and importance. The way and manner in which these functions are positioned by the architect and the connections they establish within each other are crucial concepts that determine the efficiency of the space. Examples of these spaces on patient bed floors are medical rooms and supply stations. Strategies for positioning these spaces can increase productivity by reducing employee travel distances and promoting spontaneous interactions and communication among staff, fostering a sense of collaboration and communication (Sailer 2007).

In addition, the layout of medicine rooms effects the visibility and accessibility of staff to both each other and to patients. Similar to the situation with patients, there are groups among hospital staff who may have different expectations, namely doctors and nurses. Within the topic of visibility, the two major actors of hospital environment show to have role specific expectations. While doctors prefer more clustered workstations in order to have faster interactions with nurses and to find their colleagues more easily, nurses' expectations differ according to their working patterns. Nurses who work for longer periods of time reported to prefer dispersed workstations (Koch and Steen 2012). While nurses prefer consciously or unconsciously to communicate with other nurses at points where their patients are in their field of vision, doctors prefer to interact with their colleagues at points where they can observe a larger area where they have a better awareness of the on-going situation (Lu et al. 2009).

Moreover, Pachilova (2013) argues that hospitals with open plan spaces, which she addresses as 'Knowledge Centers' in her study, host more caregiver-caregiver interactions than hospitals with a hospital plan with a hospital typology she describes as conventional. With the effect of the space, caregivers communicate with each other more frequently. On the other hand, in hospitals with conventional plan types, this encounter and exchange of ideas last longer and appear to be more planned in comparison to the other typology (Pachilova 2013). Furthermore, planned and coincidental encounters between nurses and doctors in their work environments strengthen communication between them and increase their ability to work together. These encounters and communication can be promoted by layout and design inputs. Furthermore, according to a study conducted by Rafferty, Ball, and Aiken (2001), nurses who had better teamwork reported higher job satisfaction, intended to continue their jobs, and had a lower burnout score. As stated, the layout can influence the care process by creating encounter points for staff, enhancing visibility, and reducing the walking distances of nurses. Nevertheless, the impact of layout extends beyond the mentioned points, as it engages in a corresponding relationship with the structural loads. This dynamic interplay significantly influences the architectural form and the building's integrity. Therefore, it is necessary to investigate how this relationship is established, its limits, and its effects.

2.2. Human Perception of Building Motion

Wind can influence structures in various ways. Furthermore, the morphology of the building plays a vital role in determining the effects of wind. The effect of the wind on the building varies depending on factors such as the environment in which it is located, the surrounding structures, the relationship it establishes with these structures, its shape, and wind speed (Davenport 1971; Gomes et al. 2005). Within these factors, the configuration of the building constitutes an input rendered by the designer and is consequently integrated into the decision-making process. In addition to meeting wind strength and safety requirements, serviceability criteria should be considered when evaluating these design decisions (Griffis 1993; Kwok et al. 2009; Kwok 2013). Accordingly, Griffis (1993) divides the serviceability limit states into three categories. These are deformation, motion perception, and deterioration. According to Griffis' definition, deformation refers to damage to nonstructural elements. Secondly, motion perception refers to the effect of vibrations that may occur in buildings due to wind or earthquakes on the comfort of building occupants. Lastly, deterioration covers "corrosion, weathering, efflorescence, discoloration, rotting, and fatigue" (Griffis 1993). While strict rules and requirements exist for the maximum deflection a building can make under events such as earthquakes and wind, motion perception, which falls under the second category, is more of a subjective assessment (Kwok 2013).

Therefore, there have been numerous studies to examine the effect of motion on human comfort and well-being through field experiments (Hansen et al. 1973; Goto 1983; Lee 1983; Isyumov et al. 1988; Isyumov and Kilpatrick 1996); motion simulator and shake table experiments (Goto et al. 1990; Shioya et al. 1992; Shioya and Kanda 1993; Denoon et al. 1999; Denoon 2000; Burton et al. 2006; Tamura et al. 2006; Denoon et al. 2011; Michaels et al. 2013). Considering these experiments, Kwok (2013) states that these studies primarily based their experiments on the single-degree-of-freedom sinusoidal motion to achieve comfort limits; however, in contrast to the predictable sinusoidal motion, wind creates more complex and unpredictable building motions, and the human perception and comfort limits of these two motions are different. The human response to motion, mainly when caused by wind, is a complicated blend of several psychological and physiological factors. These factors include tactile, vestibular, proprioceptive, kinesthetic, visual, and auditory cues and visual-vestibular interaction (Kwok 2013).

It is likely for extreme wind events to cause panic and alarm to occupants. However, these events are infrequent. Constant and frequent vibration is brought on by long-duration wind events that occur frequently, like synoptic storms and monsoon winds. Additionally, it has been demonstrated that building occupants subjected to longer durations of vibration are more likely to complain and feel discomfort than those subjected to the same degree of vibration for a shorter period. Furthermore, when examining the impact of wind events on human comfort, Burton et al. (2007) points out the importance of duration. Burton and colleagues stated that occupants who experience longer durations of building vibration are more likely to feel discomfort and complain than those who experience the same vibration magnitude but for a shorter duration. Moreover, according to Kwok (2013), long-term exposure to building motion can cause discomfort, headaches, dizziness, and nausea and impact the efficiency of daily task performance.

On the other hand, Chang (1973) and Johann (2015) argue that the length of a vibration has little impact on human response if it lasts longer than 5-8 seconds. If the duration of a vibration is shorter than 5 seconds, then acceptable acceleration can be raised by a ratio of 10 milli-g for 5 seconds and 20 milli-g for 2.5 seconds. However, most wind-induced vibration situations have durations longer than 5 seconds. Therefore, they exclude the length of vibrations from comfort requirements (Chang 1973; Johann 2015). Regarding the concept of wind duration, Kwok (2013) points out that although both Sydney and Brisbane Airport Control Towers meet the requirements specified by ISO6897: 1984 (International Organization for Standardization 1984), more wind-related complaints were recorded for Sydney Tower. Kwok (2013) explains that the Sydney Tower and Brisbane Airport Control Towers have different wind exposure durations. The Sydney Tower is exposed to longer-duration winds, while the Brisbane Airport Control Towers are exposed to shorter-duration but more robust winds. He emphasizes that the duration of wind exposure and the shape of the wind motion are critical factors in evaluating human perception of motion and tolerance thresholds (Kwok 2013).

Two major measures are used when evaluating wind-induced acceleration in a building: peak acceleration and root mean square acceleration (RMS). The first view implies that people tend to forget the minor vibrations and comfort and reaction are characterized by the most extensive cycle. The alternative perspective articulates that the frequency of building motion and human comfort relation depends on the number of cycles above the threshold and the intensity of these cycles (Griffis 1993; Boggs and Peterson 1997; Johann 2015). Furthermore, according to Boggs and Peterson (1997), the experimentally obtained RMS acceleration data are more consistent with the observational data than the experimental peak acceleration results. In addition, since RMS acceleration is more straightforward to calculate than Peak acceleration, evaluations based on this value seem more likely to be based on a single standard (Boggs and Petersen

1997). While peak acceleration assessment gives valuable insight into the building occupants' alarm states on wind-induced motion, RMS acceleration provides a more accurate evaluation of the comfort levels (Kwok 2009).

2.2.1. Limits for Wind Induced Vibrations

The effect of building vibration on human comfort has been investigated by several researchers (Chen and Robertson 1972; Chang 1973; Irwin 1978; Kanda et al. 1994), and more than one criterion has been proposed on the effect of vibration on human comfort (ISO 2631-1 1997; BS 6841 1987; ISO 2631-2 2003). Chang (1973) was among the first to tackle the issue by quantifying it, drawing from aircraft industry insights to suggest peak acceleration thresholds for various comfort levels. According to Chang, these limits can be summarized as follows: For a Peak Acceleration Comfort Limit of less than 0.5% g, it is virtually unnoticeable. From 0.5% to 1.5% g, it starts to become noticeable. Between 1.5% and 5.0% g, it is considered annoying. When acceleration hits 5% to 15.0% g, it escalates to very annoying. Anything above 15% g is simply intolerable.

Afterward, Melbourne and Cheung (1988) presented a method for assessing comfort levels, focusing on peak acceleration, and considering the effects of duration and frequency. Melbourne and Palmer further developed this initial framework in 1992, introducing the idea of including recurrent intervals as an additional factor in their model, thus enhancing the original concept (Melbourne and Palmer 1992). Isyumov (1993) conducted research that suggests that peak acceleration can be used to establish acceptance criteria for repeated intervals of 1 and 10 years. Based on the study, two peak acceleration ranges were identified for the 1-year return period. These ranges are 5-7 milli-g for residential buildings and 9-12 milli-g for office buildings (Figure 2.1, 26).

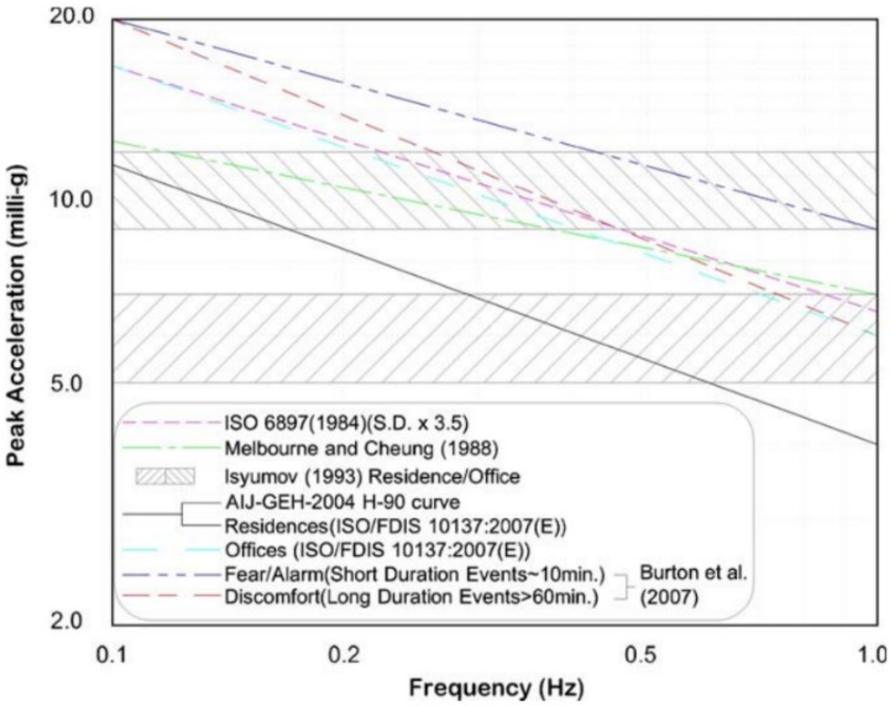


Figure 2.1. Criteria for Occupant Comfort and Serviceability Over a One-Year Return Period (Kwok, 2009)

Furthermore, according to the handbook for Australia and New Zealand (AWES-HB-001-2012) (Holmes et al. 2012), buildings that frequently experience wind-induced vibrations that exceed 10 milli-g in peak accelerations are unlikely to be acceptable to most occupants. According to a study conducted by Kwok and Hitchcock (2008), it was discovered that individuals experienced less discomfort with a decrease in acceleration levels. Specifically, the study revealed that around 90% of participants found a peak acceleration of 25 milli-g at a particular motion frequency uncomfortable. In contrast, about half of the participants found 18 milli-g peak acceleration uncomfortable.

ISO 10137 (2007) proposes two evaluation curves for a one-year return period windstorm: residences and offices. Moreover, Sarkisian (2012) suggested criteria of perception to motion in tall buildings. For residences with a one-year or a 10-year return period wind, peak accelerations of 5-7 milli-g or 12-15 milli-g were observed, respectively. For offices, peak accelerations of 10-13 milli-g or 20-25 milli-g were observed with a one-year or a 10-year return period wind (Figure 2.2, 27).

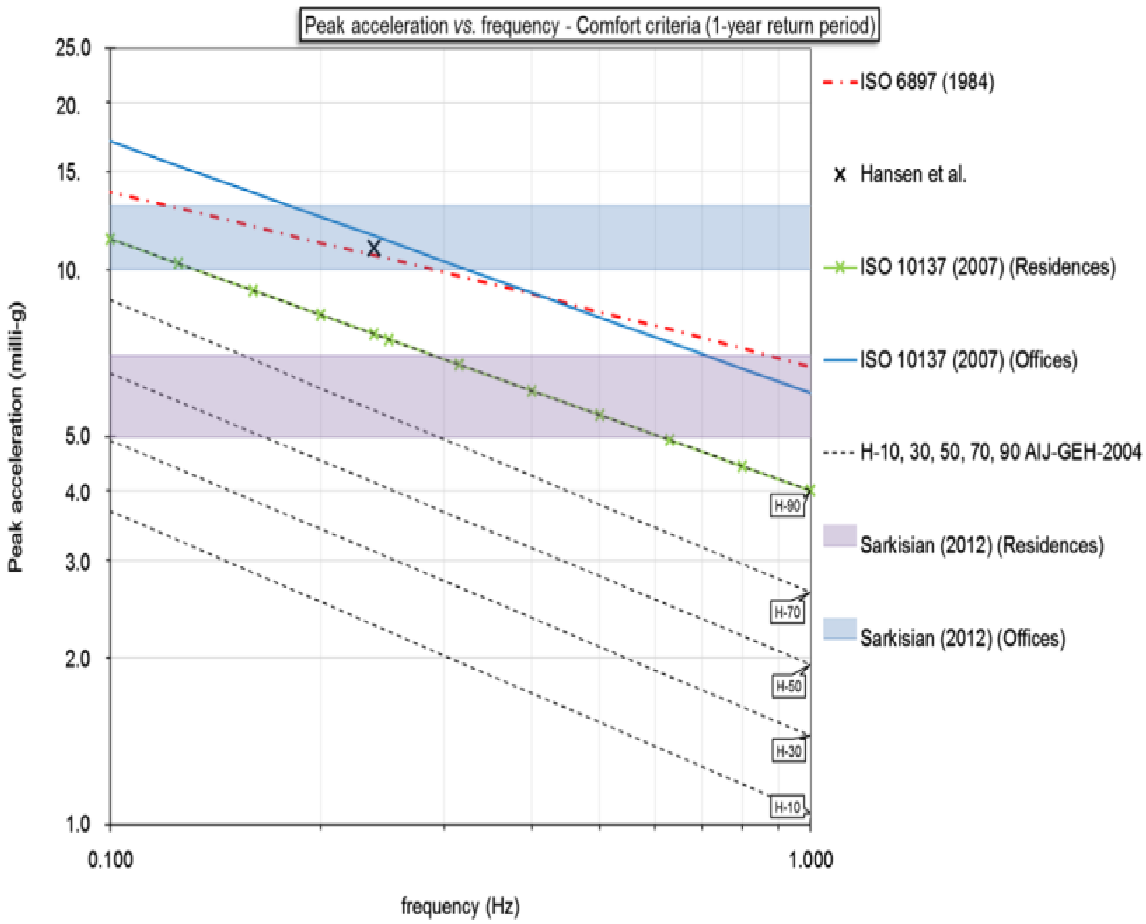


Figure 2.2. Peak Acceleration-Based Occupant Comfort Limits (Ferrareto et al. 2014)

In addition, in the case of hospitals, medical equipment with vibration sensitivity limits other than occupant comfort should also be considered in the threshold assessment. However, the vibration limits used in the literature generally depend on the human comfort and the structural integrity of a building (ASHRAE 2011; Zhu et al. 2014). As Zhu (2014) points out, these limits are too high for highly sensitive medical equipment, and the limits given and the units on which medical equipment evaluations are based are not the same. In this manner, Zhu et al. (2014) conducted a questionnaire with healthcare professionals; he and his colleagues defined 33 vibration-sensitive medical equipment. The determined limits of the questionnaire are given in Table 2.1 (Zhu et al. 2014). It should be noted that the vibration limits for medical equipment were investigated on the vibrations due to construction activities.

Table 2.1. Vibration Limits of Ultraprecision Equipment (Zhu et al. 2014; Wang et al. 2023)

Velocity curve (μm/s)	Operation category or item information
400	Optical, centrifugal, balance, separation
300	Cell processing system
200	Optical, centrifugal, radioactive substance inside
100	Optical, centrifugal, microscope
50	Delta range analytical balance
25	Genetic analyzer applied biosystems

In support of Zhu's (2014) argument for the need for lower limit values, there has also been research on the vibration limits of medical equipment caused by human activities on floors (Ungar 2007; Tigli 2014; Avci et al. 2019). The maximum allowable footfall-induced vibrations for ordinary operating rooms (Figure 2.3b, 28) should not exceed 4,000 μin/sec for RMS and 5,600 μin/sec for peak (Ungar 2007). As demonstrated by Ungar (2007), there are certain operating rooms that require extra sensitivity, such as those used for neurosurgery or microsurgery. To maintain the necessary level of precision for these rooms, a widely used criterion is one-fourth of the criterion for ordinary operating rooms. This amounts to 1,000 μin/sec, equivalent to 25 μm/s. Unlike the criterion for ordinary operating rooms, this criterion is not based on tactile perception but on microscopes and sensitive equipment (Ungar 2007).

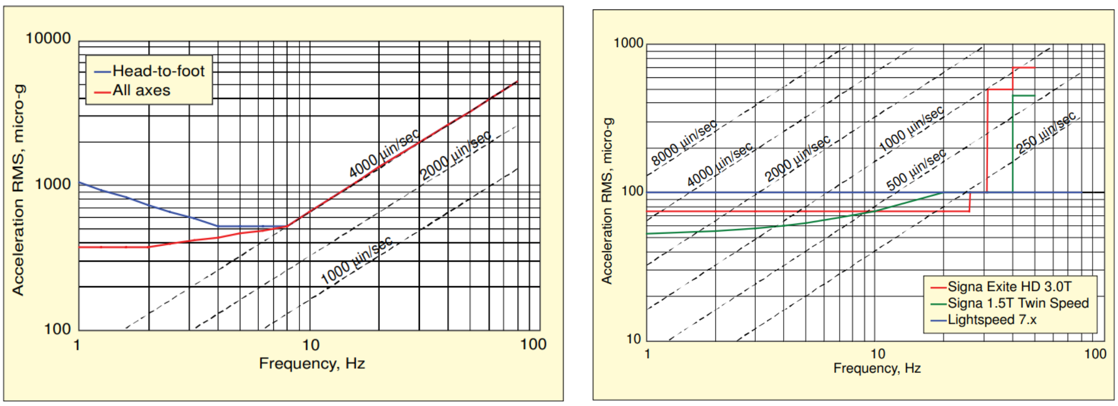


Figure 2.3 a) Human Perception Criteria b) General Electric MRI Vibration Criteria (Ungar 2007)

Furthermore, in his research, Tigli (2019) investigated issues with using an electric microscope in the operating room caused by the water pump operating at 21 Hz on the upper floor. As a result of his research, he pointed out that the limit values given by Ungar were sufficient in the mentioned case, and the vibration criterion may be different for different electric microscopes. As a result, he concluded that the vibration in the microscope eye could be determined with a maximum of 3,500 mips (Tigli 2019).

Consequently, healthcare facilities require establishing distinct threshold parameters owing to their intricate nature and critical role, the diverse daily activities proposed by the occupants with different profiles, and the specialized medical equipment they accommodate. As Tigli (2019) mentions, the suggested limits by the literature do not discriminate spaces according to their functions. The vibration and motion perception of the customers dining in restaurants and the staff working there are not the same (Tigli 2019). A similar situation applies to hospitals. The limits required for working nurses and doctors, those required for inpatients under critical treatment, and those required for medical equipment are different.

CHAPTER 3

METHODS

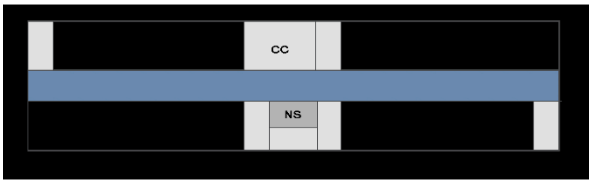
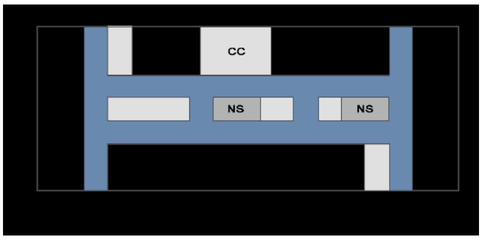
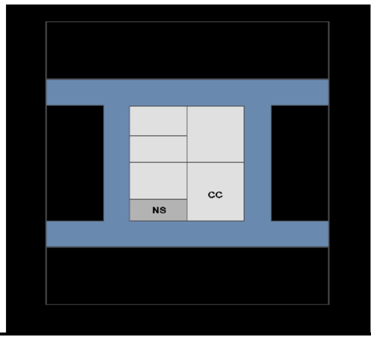
The aim of this chapter is to introduce the hypothetical inpatient floors created within the scope of the thesis to examine the relationship between morphology and wind and to briefly explain the calculation procedures. For this purpose, first, the building types and the calculation matrix to facilitate a comprehensive understanding of the analytical procedures will be introduced. Additionally, the integration of a Java program designed to enhance the calculation process will be highlighted. Then, a simplified explanation of the mentioned codes used within this framework will be given. The assumptions made based on the calculations will then be presented. Finally, the motion perception calculation will be explained.

3.1. Calculation Models

The plan types presented in this section were derived from the information obtained in the literature review summarized in Chapter 2. The main objective was to establish a basis for comparability and ensure that these plan types serve as representative models for typical layouts on existing inpatient floors. It was imperative that these representations continued to be utilized despite originating in different eras. Although some generic plan typologies were used, it was an important input to ensure that each plan type was comparable. To achieve this comparability, the structural axis spacing, room type, and auxiliary spaces were kept unchanged. The unchanging spaces mentioned above were integrated into these generic layouts while remaining faithful to their working principles.

Although all these plan types - single corridor, racetrack, and Compact Square (Table 3.1, 39) - are variations of the rectangular form, they propose different aspect ratios. Accordingly, the prominent phenomenon to be questioned here is the relationship of architectural decisions arising from the functioning schemes of these space examples with similar capacities with structural loads. The study considers the wind load and examines its relationship in more detail. To obtain some of the data needed for calculating wind loads, additional data for these plan diagrams had to be provided.

Table 3.1. Plan Schemes

Model Type	**Plan Diagram**
Single Corridor	
Racetrack	
Compact Square	

Note. NS refers to the nurse station and CC refers to the circulation core.

The additional data required for wind calculations were window sizes, building dimensions, roof type, and environmental parameters. The generic plan types have been detailed to provide the necessary data for this floor type by using the pre-determined room. Data such as environmental factors, building height, and roof type were obtained by making separate calculations for each possibility, providing the necessary details for these plan schemes. The additional data required for wind calculations were window sizes, building dimensions, roof type, and environmental parameters. In order to track this multivariate process efficiently, a six-digit code system was developed that also expresses the characteristics of the buildings. Each digit was assigned with a changing variable and used these building definitions as descriptors to introduce these buildings to the Java program that has been created.

The following section will present a more thorough explanation for each proposed plan type and will provide more detailed information on the dimensioning and schematics of the proposed plan types. In addition to that, explanations for the assumptions for calculating wind loads will be presented.

3.1.1. Type 1: Single Corridor

The building model Type 1 has a single corridor plan type with building geometry code 1. The room type, determined as standard and representing the majority, was used for this plan type. Although there is a trend towards using single rooms in patient inpatient rooms today, the rooms in this thesis were designed for two people to represent the majority.

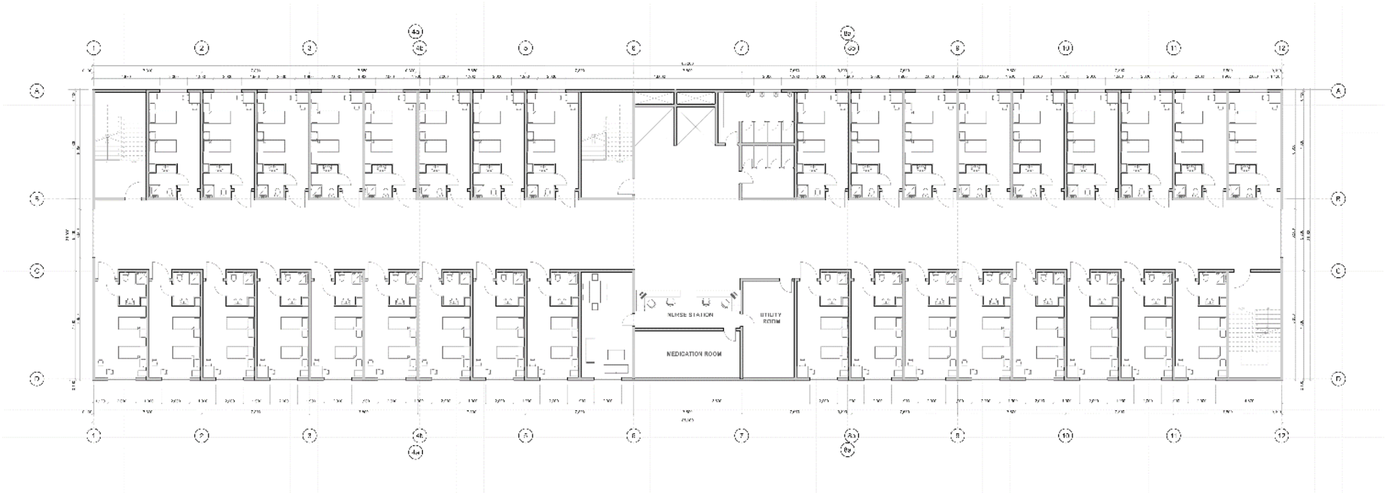


Figure 3.1. Single Corridor Type 1 Plan

The structural axes are created depending on the size of these rooms. For building type 1, these axes are 7.8 m, and the central axe, which provides the main circulation, is 5.2 m. The circulation core is located at the center of this axe with the nursing station. The nurse stations are positioned opposite the main horizontal circulation to ensure surveillance and control. In addition to the main vertical circulation core, there are secondary vertical circulation elements on both corners of the plan, facing each other. The utility and medication rooms are located next to the nursing unit for easy access. The plan type has 36 patient rooms, which equals 72 patient capacity for one floor. The sum area of the whole floor is 1.805,863 square meters. Accordingly, the area-patient ratio for this type is obtained as 28.05. Depending on the size and layout of the rooms, the plan type measures 21 meters by 86 meters. Therefore, the aspect ratio, one of the critical values regarding wind loads, is calculated as 4.09 for this plan type. At the 4th and 8th axes, there are two dilatations at 23.5 and 31.3 meters from the corners.

3.1.2. Type 2: Racetrack

Building type 2 refers to a plan layout known as the Racetrack layout. In this plan type, the service units that feed the space are located on the central axis, while the circulation is shaped around these core units. While creating this representative building plan, the same room elements as the previous representative plan model were used. The axes that constitute the structural system of the building were also created based on the dimensions of this room element, again at intervals of 7.8 and 3.9 meters. The central vertical circulation core is located at the center of the plan, as in the previous model. This model includes two nursing stations. The main one is located in relation to the central circulation core to provide the nurses with the necessary floor surveillance. Apart from the central circulation, the floor consists of two additional vertical circulation cores at each side of the plan. The utility and medication rooms are near nursing stations to decrease walking distances and improve access.

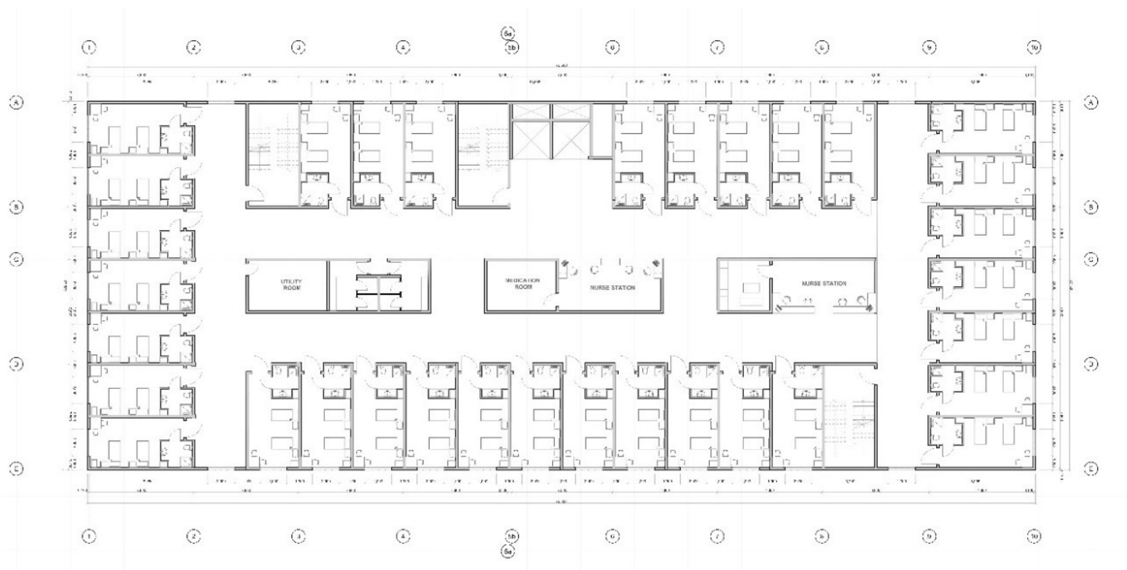


Figure 3.2. Racetrack Type 2 Plan

Additionally, each floor contains 33 patient rooms, which results in each floor having the capacity to accommodate 66 patients at once. The external dimensions for this plan type are 70.6 meters by 27.5 meters. Accordingly, the aspect ratio is 2.56, and the floor area of the plan is equal to 1.941,664 square meters. Therefore, based on the dimensions and values above, the area-patient ratio is 30,33. For this plan type, there is dilatation at the 5th axis level.

3.1.3. Type 3: Compact Square

Although the plan type, Compact Square, is the same as the Racetrack regarding the working principle within the floors themselves, the reason for taking this plan type as a separate model is to examine the relationship between the differences in aspect ratios and wind loads.

Figure 3.3. Compact Square Type 3 Plan

This plan type also has a circulation core and service spaces at the plan's center. The central vertical circulation core is situated in this compartment where the service spaces are located. The nurse station is placed next to the central vertical circulation element to allow the observation of entrances and exits. The utility and medication room are within this core region. The plan consists of the same standard room as the previous examples. Correspondingly, the structural axes are 7.8 meters wide. However, the circulation spaces are flanked by axes with a width of 3.9 meters. The plan is a square with external dimensions of 39.2 meters by 39.2 meters. Due to its square form, its aspect ratio is determined as one. As a result, the floor area of this plan type is 1.537,127 square meters. Each floor accommodates 56 patients and 28 patient rooms. Relatively, the area-patient ratio is 27,45.

3.2. Calculation Matrix

The primary purpose of creating a computation matrix is to enhance the readability of the study and facilitate the tracking of calculations. The study assigns codes to variables influenced by architectural decisions and building location. Each hypothetical building has a unique code, which represents the characteristics of the building proposed by each letter. The code is designated as idjkpz, with the number corresponding to each digit. The key is as follows: i (floor plan type), d (building direction) j (building height), k (roof type), p (roof pitch) and z (exposure category). For example, building 1x52a1 indicates a 15-story, that has a mono pitched roof with %5 pitch and has a single corridor plan type with the x direction and is in the type B exposure zone as specified by ASCE 7.

Table 3.2. Building Geometry Codes

Geometry Code (I)	Inpatient Unit Layout Type	Number of Patients	Aspect Ratio	Area (m^2)	Number of NS	Area-patient ratio
(I=1)	Single Corridor	72 (36*2)	4,09	1.805,863	1	25,08

Table 3.2. Building Geometry Codes (cont.)

(I=2)	Racetrack	66 (33*2)	2,56	1.941,664	2	30,33
(I=3)	Compact Square	56 (28*2)	1,00	1.537,127	1	27,45

As indicated in Table 3.2 (35-36), three plan types were selected to create three different geometries for the study. Two codes, EN1991-1 and ASCE 7, were used for the calculations for the three types mentioned. Two rectangular plan types with different aspect ratios depending on the positioning of the service spaces were used. In addition, although the principle of in-floor operation is the same as the racetrack, the Compact Square examination was also included in the study due to the difference in aspect ratio.

Table 3.3. Building Height Codes

Height Code (J)	**Floor Number**
(J=1)	3
(J=2)	4
(J=3)	6
(J=4)	9
(J=5)	15
(J=6)	20

A series of calculations by varying the height factor to establish the level of influence the height factor has been conducted. These buildings were classified as low-rise, mid-rise, and high-rise. Moreover, two examples from each category were implemented. Buildings with 3, 4 floors are categorized as low-rise, buildings with 6, 9 floors as mid-rise, and buildings with 15, 20 floors as high-rise.

Table 3.4. Roof Type Codes

Roof Code (K)	Roof Type
(K=1)	Flat Roof
(K=2)	Monopitch Roof
(K=3)	Duopitch Roof
(K=4)	Hipped Roof

The roof types specified in the roof type table (Table 3.4, 36-37) are specified as defined by EN1991-1. Each hipped roof type's calculations involve three scenarios with 5%, 30%, and 60% roof slopes. The *p* input in the building code is the letters: "*a*" for 5%, "*b*" for 30%, and "*c*" for 60%. The building codes have no *p* input for the flat roof type. For the hypothetical calculations with flat roof type, it is assumed that these buildings have parapet walls with a height of 0.025 of the building height.

Table 3.5. Exposure Category Codes

Exposure Code (Z)	Exposure Category
(Z=1)	B
(Z=2)	C
(Z=3)	D

The exposure category table (Table 3.5, 37) employs the exposure categories defined by ASCE 7. This is mainly because the EN1991-1 has more categories. To avoid the dichotomies that may arise and to make the calculations more comparable, the terrain categories in EN1991-1 were matched with the categories in ASCE 7 based on the definitions in the codes. Based

on the dichotomies above, exposure category B in ASCE 7 with terrain category IV in EN1991-1, Exposure C with terrain categories II and III, and Exposure D with terrain categories 0 and I were matched.

3.2.1. Computation Process

Due to the large number of variable parameters and variations to be used in the planned calculations, it was foreseen that Java code would be used to make the calculation process more efficient and controllable. One of the purposes of creating this Java code was to facilitate the comparison between the calculation types and to automate the changes in some of the units used and the values taken.

```
        System.out.println( x: "Çatı eğimi 60");
    }
    default -> {
    }
}
switch (buildingCodeArray[buildingCodeArray.length - 1]) {
    case "1" -> {
        a.terraincategory = "Terrain Category IV";
    }
    case "2" -> {
        a.terraincategory = "Terrain Category II";
    }
    case "3" -> {
        a.terraincategory = "Terrain Category 0";
    }
    default -> {
    }
}
a.cdir = 1;
a.cseason = 1;
a.cz0 = 1;
a.projectname = buildingcode;
a.dominantface = false;
a.vb0 = 27.0;
eurocodeCalculator(a);
try {
    ASCECalculator(a);
} catch (Exception e) {
    System.err.println("Error processing row " + rowIndex + ": " + e.getMessage());
    continue;
}
a.ArzASCE = AccelerationCal(a,  x: a.windwardpressure)[1];
a.TASCE = AccelerationCal(a,  x: a.windwardpressure)[0];
a.ArzEuro = AccelerationCal(a,  (a.zonepressureA / 47.880208))[1];
a.TEuro = AccelerationCal(a,  (a.zonepressureA / 47.880208))[0];
```

Figure 3.4. Java Code

While doing this programming, a building code class where the data is stored, and the building is defined was created. In addition, all the data required for the calculation was defined within this class. Secondarily, two different calculation methods, EN1991-1 and ASCE were developed. The conversion of different units to each other were solved within these methods. In the following sections, detailed explanations of our assumptions will be presented to the reader. In the main class where the calculations are made, the specified building types and building codes were introduced to the program depending on their specifications (Figure 3.4, 38). The program pulls these building codes from the Excel file and then redefines them again in the same file after performing the calculations.

3.3. Wind Calculation Methods

Architectural decisions such as layout plans, openings, building shape, roof type, context, and building positioning have a huge impact on wind loads. According to Arvindbhai, some of the factors that affect the micrometeorological and aerodynamics of a structure are “shape and size of the structure, wind incidence angle, interference effects of other buildings, dynamic properties of the structure, and wind characteristics” (Arvindbhai 2008). The analysis of the wind forces acting on the structure is one of many aspects that determine the building's structural system. Architects need to consider how their design approaches and decisions determine the wind load as well. Although, EN1991-1 and ASCE 7-22 suggest similar roadmaps (Figure 3.5, 40) for calculating wind loads, there are differences in coefficients, formulations, and environmental factors (Table 3.6, 39).

Table 3.6. Comparison of Formulations

Calculated Value	**EN1991-1**	**ASCE 7-22**
Basic Wind Speed	$v_b = c_{dir} \cdot c_{season} \cdot v_{b,0}$	From table 26.5
Peak Velocity Pressure	$q_p(z) = [1 + 7I_v(z)]. \frac{1}{2}. p. v_m^2(z) = c_e(z). q_b$	$q_z = 0{,}616. K_z. K_{zt}. K_d. K_e. V^2$ $q_z = 0{,}0256. K_z. K_{zt}. K_d. K_e. V^2$
Wind Pressures	$w = c. q$	$p = qGC_p - q_i(GC_{pi})$
Wind Force	$F_w = c_s c_d. c_f. q_p(z_e). A_{ref}$	$F = q_h. G. C_f. A_s$

These variations increase the likelihood of ambiguity between ASCE 7-22 and EN1991-1 users. Furthermore, the effect of wind load on hospital buildings is a crucial subject for consideration in the cladding design and construction of healthcare facilities.

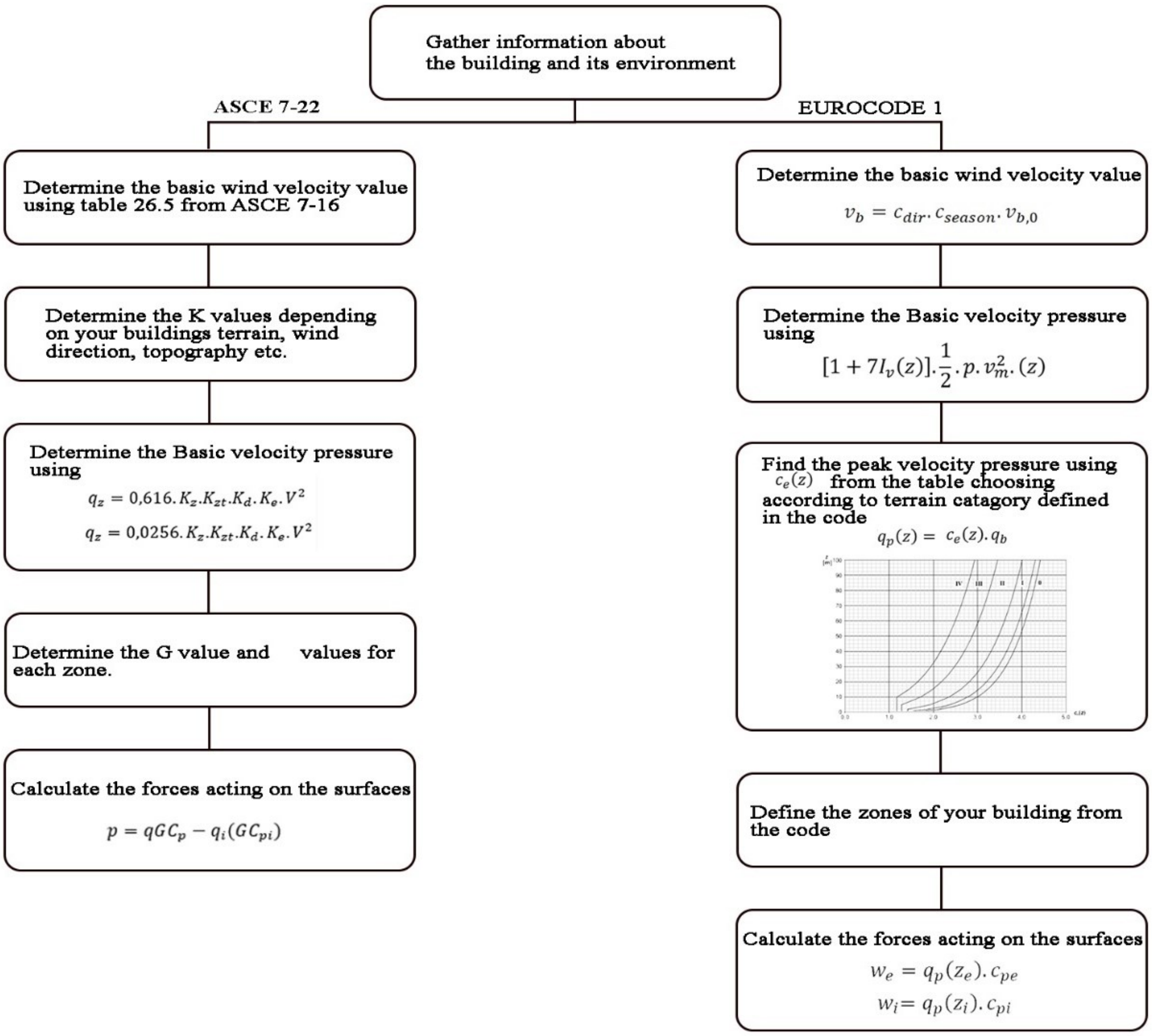


Figure 3.5. Flowchart for Calculations

In the process of designing a building mass, some significant features affect the wind loads. Building shape selection and corner modifications improve the wind response of a building to wind forces (Merrick and Bitsuamlak 2009). According to Kwok (1998), "horizontal slots, slotted corners, and in particular chamfered corners" are effective for reducing wind loads for buildings. The modifications on the corners are defined in two groups: "minor modifications (corner cut, rounding, chamfer, etc.) and major modifications (taper, set-back, twist, etc.)" (Sharma et al. 2018). Thus, while designing the shape of a building, the corner design needs to be taken into consideration as well. Building construction costs may increase due to improper form selection, particularly when the planned complex grows. Another issue that needs to be considered is the environment of the building. It is proven that other buildings surrounding the building change the wind forces acting on structures (Nagar1a et al. 2020).

The additional improvements of healthcare facilities over time, such as adding new units, can affect the wind loading on an existing structure. This adaptation process is necessary to include new spaces for technology advancements, additional inpatient units, and other new requirements of the hospitals that may occur after the construction of the building.

In the next sections of this chapter, the authors will provide a quick overview of the two mentioned codes, explain the computer program that is created to calculate and compare wind pressures, compare the two methods, and lastly explain the assumptions that have been made.

3.3.1. EN1991-1

EN1991-1 is a set of standards for structural design in Europe. The code EN 1991-1-4, published by the European Union in 2005, provides a comprehensive framework for calculating wind loads on buildings and other structures. These calculations provide an essential basis for maintaining the structure's structural integrity in the face of wind loads. Considering different conditions, the wind calculation considers factors such as wind direction, seasonal variations, terrain characteristics, and building morphology to calculate the exact wind load.

The first action to be taken when starting the EN1991-1 calculation is determining the basic wind velocity (Eq. 1, 49). In Eq. 1, V_b is the basic wind velocity, C_{dir} is directional factor, C_{season} is seasonal factor and, $V_{b,0}$ is the fundamental value of the basic wind velocity. In doing so, the base wind speed is modified with the coefficients specified in the code. The value of the base wind speed refers to the characteristic 10-minute average wind speed (European Committee for Standardization 2005). Therefore, as stated in Eq.1, this value is multiplied by the directional and seasonal factors to derive the basic wind speed. For both directional and seasonal factors EN1991-1 suggest using National Annex's, but it is always recommended to use these values as 1,0.

$$V_b = C_{dir} \, . \, C_{season} . \, V_{b,0} \quad (1)$$

V_b: Basic wind speed (m/s)

C_{dir} : Directionality factor

C_{season}: Seasonal factor

$V_{b,0}$: 10-minute average wind speed (m/s)

For the EN1991-1 approach, basic wind velocity depends on air density, exposure factor, and basic velocity pressure. The peak velocity pressure is calculated on regional wind climate, local factors (e.g., terrain roughness and orography), and the height above the terrain. As stated in Equation 2, according to EN1991-1, three values are needed to calculate the mean wind velocity. The last of these values is V_b, is the basic wind velocity as explained in the previous step. The second value is the orography factor, $c_0(z)$, which can be taken as 1 unless otherwise specified in the National Annex or EN1991-1 4.3.3. For the roughness factor, $c_r(z)$, other calculations must first be made to obtain this value. In the equations below, k_r is the terrain factor, z is the height above ground, z_0 is the roughness length, and $z_{0,II}$ is the roughness length in terrain II (0,05 m).

$$V_m(z) = c_r(z). c_0(z). V_b \qquad (2)$$

$$c_r(z) = k_r. \ln\left(\frac{z}{z_0}\right) \qquad (3)$$

$$k_r = 0{,}19 \,.\left(\frac{z_0}{z_{0,II}}\right)^{0{,}07} \qquad (4)$$

$V_m(z)$: Mean wind speed at height z (m/s)

$c_0(z)$: Gust response factor at height z

$c_r(z)$: Velocity pressure exposure coefficient at height z

k_r: Roughness length correction factor

z_0: Roughness length (m)

Table 3.7. Terrain Categories Adapted from Table 4.1 in EN1991-1

Terrain Code	**Explanation**	z_0	$z_{0,II}$
0	Ocean, sea, or a coastal region that faces the open sea.	0,003	1
I	Areas that are flat, without obstacles, and have sparse vegetation are known as lakes or plains.	0,01	1

Table 3.7. Terrain Categories Adapted from Table 4.1 in EN1991-1 (cont.)

II	Refers to an open space with short vegetation like grass and few scattered obstacles such as trees or buildings. The distance between these obstacles should be at least 20 times the height of the obstacle.	0,05	2
III	Refers to an area that has a consistent covering of vegetation or buildings, or has individual obstacles spaced apart by a maximum distance of 20 times the height of the obstacle. Examples of such areas include villages, suburban landscapes, and permanent forests.	0,3	5
IV	An area is considered to fall under this category if more than 15% of its total surface is occupied by buildings of 10 meters or higher, on average.	1,0	10

To calculate this value, a two-step calculation is required. First, however, the terrain category of the building must be determined (Table 3.7, 42-43). After determining the terrain category according to the definitions given in Table 3.7, the k_r value is needed first to calculate the roughness factor (Eq. 3, 50). This value is calculated as given in Formula 4, and the required data is selected according to the terrain category from Table 3.7. After obtaining the required values from the table and calculating k_r and accordingly, the next step is calculating the wind turbulence value given in EN1991-1 to consider the turbulence effect (Eq. 5, 51). To calculate this value, an extra value, k_l, is needed which is the turbulence factor and given as 1 unless otherwise stated in the EN1991-1 and the national annex. For the $c_0(z)$, given in Eq. 5, the calculation is made with the value taken when calculating $V_m(z)$.

$$I_v(z) = \frac{k_l}{c_0(z).\ln(z/z_0)} \quad (5)$$

$I_v(z)$: Turbulence intensity at height z

k_l: Turbulence length scale factor

$c_0(z)$: Gust response factor at height z

z_0: Roughness length (m)

After all these operations are completed, the peak velocity pressure calculation is carried out. Since the $I_v(z)$ and $V_m(z)$ values needed to calculate the peak velocity pressure are already obtained, air density is the only value that needs to be known. As for all other values, this value is taken for air density unless otherwise specified in the national annex or EN1991-1. An alternative way to calculate the peak velocity pressure is also given in the second half of Equation 6. This alternative calculation is based on the same values. However, the value of $c_e(z)$ is obtained from Figure 4.2 in EN1991-1 (Appendix B.1, 114) depending on the terrain category and z. The q_b is calculated based on the basic wind velocity V_b and air density as in Equation 7.

$$q_p(z) = [1 + 7.I_v(z)].\frac{1}{2}.\rho.v_m^2(z) = c_e(z).q_b \tag{6}$$

$$q_b = {}^1/_2.\rho.v_b^2 \tag{7}$$

$q_p(z)$: peak wind pressure at height z (Pa)

ρ: air density (kg/m³)

$I_v(z)$: turbulence intensity at height z

q_b: reference mean (basic) velocity pressure

$c_e(z)$: exposure factor

The last action to be taken after all the steps have been completed is to determine the wind pressures acting on surfaces. There are two values needed to do this. The first of these values, $q_p(z)$, has already been obtained. When calculating the surface pressures, it is crucial to determine the coefficients for each surface correctly. In this process, the pressures acting on the inner surfaces and the pressures acting on the outer surfaces are calculated separately. The total pressure acting on these surfaces is obtained by summing these two values. Accordingly, each zone must first be analyzed with its dimensions, and then the coefficients of these zones given by EN1991-1 must be determined. While doing this, according to EN1991-1, a calculation should be made for the calculation of the value defined as internal pressure acting on the internal surfaces of the building (Eq. 8, 52).

$$w_i = q_p(z_i).c_{pi} \tag{8}$$

w_i: internal wind pressure

c_{pi}: internal pressure coefficient

q_p: peak velocity pressure

As stated in EN1991-1 bullet 7.2.9, the c_{pi} is determined depending on the openings of the building, and in this direction, it is first checked whether the building has a dominant face. When a building's area of openings on one face is at least double that of openings and leakages on the other faces under consideration, that face of the structure is referred to as dominant face. If the building has a dominant face, the c_{pi} can be determined by one equation related to c_{pe} , the external pressure coefficient. When the dominant face has openings at least twice as the other faces, the c_{pi} equals 0,75 times c_{pe}. On the other condition, where the dominant face has at least three times more opening than the other faces, the c_{pi} equals 0,90 times c_{pe}. In the cases where the building doesn't have a dominant face, the c_{pi} can be determined by using Figure 7.13 in EN1991-1 (Appendix B.2, 114). The μ required to find c_{pi} from the table can be found with equation 9. After this value is obtained, the c_{pi} depends on the h/d ratio, and interpolation is performed for the values between the h/d ratios (0.25 and 1) specified in Figure 7.13 (Appendix B.2, 114) in EN1991-1.

$$\mu = \frac{\sum \text{area of opennings where } \mathrm{c_{pe}} \text{ is negative or } -0{,}0}{\sum \text{area of all opennings}} \tag{9}$$

A process similar to the calculation of wind pressure acting on internal surfaces is also managed for external surfaces. The recommended values for c_{pe} are selected from Table 7.1 depending on the h/d ratio for the walls of the building. Interpolation is performed for values between the given h/d ratios. Depending on the roof type of the structure, the required coefficients are obtained from section 7.2 of the EN1991-1.

$$w_e = q_p(z_e).\, c_{pe} \tag{10}$$

w_e: external wind pressure

c_{pe}: external pressure coefficient

q_p: peak velocity pressure

As a result, EN1991-1 standards provide a standardized methodology for calculating wind loads and designing durable buildings. It takes into account regional differences, site characteristics, and structural qualities. It enables engineers to make informed decisions and develop structures prioritizing safety and durability.

3.3.2. ASCE 7-22

ASCE 7-22 Minimum Design Loads and Associated Criteria for Buildings and Other Structures is a code provided by the American Society of Civil Engineers. This code includes calculation methods for live loads, snow loads, wind loads, flood loads, rain loads, tsunami loads and effects, and seismic loads. This thesis will only cover the section related to wind loads. The ASCE 7-22 examines the wind loads in two subcategories: the wind loads affecting main wind force resisting systems (MWFRS) and Components and Cladding. When the structure doesn't match the criteria described in the code, ASCE 7-22 recommends the user conduct a wind tunnel experiment. The requirements for wind tunnel experiments are in Chapter 31 of the code under the name Wind Tunnel Procedures. Therefore, this thesis will focus on MWFRS calculations. The code also provides user tables that give calculated values for enclosed buildings, which will be further examined in correlation with EN1991-1 in the following sections.

ASCE 7-22 general requirements for wind loads start with the definitions for the terms used in the calculations and a road map for the users. The main calculation formula given in the code is the effective dynamic wind pressure at height z (11,12). The ASCE 7-22 interdepends the peak velocity pressure on wind directionality, topography, ground elevation, basic wind speed, and velocity pressure exposure. The code then guides the user to determine each value in the equation.

$$q_z = 0.00256 K_z K_{zt} K_d K_e V^2 \left(\frac{lb}{ft^2}\right); \text{ V in mi/h} \tag{11}$$

$$q_z = 0.613 K_z K_{zt} K_d K_e V^2 \left(\frac{N}{m^2}\right); \text{ V in m/s} \tag{12}$$

K_z:velocity pressure exposure coefficient
K_{zt}: topographic factor
K_d: wind directionality factor
K_e: ground elevation factor
V: basic wind speed
q_z: velocity pressure at height z.

The first thing to determine before starting the calculation is the Exposure Category. According to section 26.7 of ASCE-22, the exposure category depends on vegetation, natural topography, and constructed facilities. ASCE 7-22 examines the exposure in three categories: B, C, and D. These categories are explained in the 26.7.3 Exposure Categories section of the code. Subsequently, the user can gather the values that are given in the equation 1 and/or 2. Each value can be gathered from its sections.

For K_z, also defined in the standard as velocity pressure exposure coefficient, users can see Table 26.10.1 in ASCE 7-22 (Table 3.3, 36). In cases where the building height is unspecified in the table, it is permitted to estimate intermediate height values through interpolation. In cases where more precise calculation is required, the equations used to construct the table are given in the code as follows (Eq. 13,14).

For 15 ft (4.6 m) ≤ z ≤ z_g $\quad K_z = 2.01\left(\frac{z}{z_g}\right)^{\frac{2}{\alpha}}$ (13)

For z < 15 ft (4.6 m) $\quad K_z = 2.01\left(\frac{15}{z_g}\right)^{\frac{2}{\alpha}}$ (14)

The z_g and α values in equations 3 and 4 should be determined from Table 3.8 (47). These values are only determined by the Exposure Category.

Table 3.8. Terrain Exposure Constants Adapted from Table 26.11-1 (Appendix B.4, 115) in ASCE 7-22

Exposure	**α**	**z_g(ft)**	**z_g(m)**
B	7.0	1,200	365.76
C	9.5	900	274.32
D	11.5	700	213.36

Table 3.9. Velocity Pressure Exposure Coefficients Adapted from Table 26.10-1 in ASCE 7-22

Height Above Ground Level		**Exposure Category**		
Ft	**M**	**B**	**C**	**D**
0-15	0-4.6	0.57 (0.70)$^{\alpha}$	0.85	1.03
20	6.1	0.62 (0.70)$^{\alpha}$	0.90	1.08
30	9.1	0.70	0.98	1.16
40	12.2	0.76	1.04	1.22
50	15.2	0.81	1.09	1.27
100	30.5	0.99	1.26	1.43
150	45.7	1.11	1.37	1.53
200	61.0	1.20	1.46	1.61

Table 3.9. Velocity Pressure Exposure Coefficients Adapted from Table 26.10-1 in ASCE 7-22 (cont.)

250	76.2	1.28	1.53	1.68
300	91.4	1.35	1.59	1.73
350	106.7	1.41	1.64	1.78
400	121.9	1.47	1.69	1.82
450	137.2	1.52	1.73	1.86
500	152.4	1.56	1.77	1.89

K_{zt}, is a multiplier used to take into account the wind speed-up effect. To calculate this multiplier, the values regarding terrain are calculated according to Figure 26.8-1 in ASCE 7-22 and substituted into the formula for K_{zt} (Eq. 15, 56). If terrain data is unavailable, ASCE 7 stipulates that this value should be taken as 1. In this context, the accepted value is 1.

$$K_{zt} = (1 + K_1K_2K_3)^2 \tag{15}$$

K_d, wind directionality factor, is given in table 26.6-1. For MWFRS the K_d value is 0,85. In the subsequent calculations, only the MWFRS calculation method will be used, therefore the value K_d will be taken as 0.85.

It is permitted for K_e, ground elevation factor, to be taken as 1.00 in all cases as a conservative approach. In cases where K_e value needs to be more precise Table 26.9-1 (Appendix B.3, 115) from the code can be used. The K_e depends on the building's ground elevation above the sea level. Lastly, for the basic wind speed ASCE 7- guides the user to Section 26.5. After estimating the peak velocity pressure (q_z) to calculate the design wind pressure for the MWFRS, ASCE supplies the following formula (Eq. 16, 56).

$$p = qGC_p - q_i(GC_{pi}) \tag{16}$$

p: Design wind pressures

q: q_z at height z above the ground.

G: gust-effect factor

C_p: external pressure coefficient

GC_{pi}: internal pressure coefficient

Based on this formula, the first thing to do is decide which height to use when calculating q. For this, different values should be taken depending on the type of building -enclosed, partially enclosed, partially open, or open - as mentioned in section 27.3.1. All building types calculated in this thesis are partially enclosed. The G value specified in the formula, gust factor, specified by the code for rigid structures, is 0.85. More detailed descriptions and calculation methods can be found in Section 26.11 of ASCE 7. For the C_p value, several coefficients are presented by the code (Table 3.10, 49). The ASCE provides the GC_{pi} as 0.55 and -0.55 for partially enclosed buildings.

To put it briefly, ASCE 7-22 provides standardized methods and coefficients for determining wind loading, ensuring that structures are designed to withstand the dynamic forces of wind with reliability and safety.

Table 3.10. Pressure Coefficients Adapted from Table 27.3-1 in ASCE 7-22

Surface	**L/B**	C_p
Windward wall	All Values	0.8
	0-1	-0.5
	2	-0.3
Leeward wall	≥4	-0.2
Sidewall	All Values	-0.7

3.3.3. Assumptions

While conducting this study, some assumptions were made in the calculation process due to the dualities and different units and values specified by the codes. These assumptions are in parallel with the values specified and recommended in EN1991-1 and ASCE 7. The assumptions used for the calculations within EN1991-1 were selected based on the values recommended by EN1991-1 (Table 3.11, 50). As suggested, these values, C_{dir} , C_{season}, $c_0(z)$, and k_l, are all set to 1. Except for these values, the air density was noted at 1.25 throughout the calculations, as stated in the code. The $V_{b,0}$ value outside these values was constant throughout the calculations and determined as 27 m/s.

Table 3.11. Fixed Values

Parameter	Fixed value
C_{dir}	1
C_{season}	1
$c_0(z)$	1
k_l	1
ρ	1,25 kg/m^3
$V_{b,0}$	27 m/s
K_{zt}	1
K_e	1
K_d	0,85
G	0,85
GC_{pi}	+0,55/-0,55

Similar to EN1991-1, for ASCE 7, some values are kept constant throughout the calculations specified in the code. While K_{zt} and K_e are taken as 1, K_d and G are set as 0.85. The K_d is based on the value recommended for the Main Wind Force Resisting System. Likewise, the recommended value of 0.85 for rigid structures was taken for gust. In addition, since all model structures defined in the thesis are partially enclosed according to ASCE 7, GC_{pi} is taken as +0.55 and -0.55.

The most significant transformation to compare these two codes was the parameter for determining the retrieved wind speed. While EN1991-1 takes the wind speed as the average value of the wind speed affecting the building within 10 minutes, ASCE is based on the highest velocity affecting the building within 3 seconds (Lungu et al. 1996). Equation 17 below was used to convert these two velocities to each other.

$$V_{ref}^{10\,min} = 0{,}67.V_{ref}^{3sec} \quad (17)$$

In addition to the mentioned transformations and values, the categories mentioned codes, the Exposure Category for ASCE and the Terrain Category for EN1991-1 which refer to terrain conditions and surrounding structures, were crossed matched with each other (Table 3.12, 51).

Table 3.12. Environmental Factor Categories Pairing

Exposure Categories	**Terrain Categories**
B	IV
C	II, III
D	0, I

3.4. Wind Induced Motion Perception

With the intention of making the effect of wind load on building occupants more understandable, in this study, the building motions induced by loads with the limit values specified in the literature were compared. To achieve this objective, the simple expressions (Griffis 1993) that give the dynamic responses of the hypothetical hospital buildings that presented in the earlier sections were followed.

In this manner, the calculated periods for each suggested building as shown in Eq. 18. In Eq. 18, T is the period, H is the building height, and ρ is the building density, , which is fixed to 15.3 pcf. The design drift ratio (D_r) specified in the formula is taken as 0.0025 (Griffis 1993). The p (equivalent uniform pressure) given in the formula expresses the value of the wind load in pounds per square foot (psf), calculated in the previous stage for each building. R is the building plan dimension (H/B) ratio, where the B value is taken as the square root of the square of the width and height of the building.

$$T = 0,904H\left(\frac{\rho D_r}{pR}\right)^{0.5} \tag{18}$$

T: building period in seconds

ρ: density (PCF)
H : building height (feet)
D_r: design drift ratio (Δ/H)
p: equivalent uniform pressure (PSF)
R: aspect ratio H/B

The Eq. 19 is used for the building's generalized stiffness, *K*. In this equation, N is the frequency (hertz) and was taken as 1/T, whereas M is the building mass.

$$K = (2\pi N)^2 \times M \tag{19}$$

K: generalized stiffness (newton/meters)
N: frequency (hertz)
M: generalized mass of the building (kilogram)

Three acceleration calculations are required when calculating RMS acceleration values: along wind, across wind, and torsional. The proportionality constants formulas that must be found for each value before these calculations are given below (Eqs. 20-23, 60). In these equations, *B* is the plan dimension of square building (meters) or square root of the plan area for rectangular shapes, Z is the height of the building, N_θ is the torsional frequency and U_H is the mean hourly wind speed (meters/sec.)

$$C_D(Z) = 0.0116 \times B^{0.26} \times Z \tag{20}$$

$$C_L(Z) = 0.0263 \times B^{-0.54} \times Z \tag{21}$$

$$C_\theta(Z) = 0.00341 \times B^{2.12} \times Z, \frac{N_\theta B}{U_H} \leq 0,25 \tag{22}$$

$$C_\theta(Z) = 0.00510 \times B^{1.24} \times Z, \frac{N_\theta B}{U_H} > 0,25 \tag{23}$$

$C_D(Z), C_L(Z), C_\theta(Z)$: proportionality constants
B: plan dimension (meters)
Z: building height (meters)
U_H: mean hourly wind speed (m/s)

The U_H value in the formulas refers to the mean hourly wind speed. The following formula (Eq. 24, 61) was used to convert this value from the 10-minute speed value used in the previous sections of the calculations (Lungu et al. 1996).

$$V_{ref}^{10\,min} = 1{,}05.\,V_{ref}^{1h} \tag{24}$$

The following formulations are used after obtaining the required values from the previous equations for along-wind (A_D), across-wind (A_L), and torsional (A_θ) accelerations (Eqs. 25-27, 61). In these equations, K_D is the generalized stiffness, ζ is the damping ratio and *M* is the generalized mass of the building (kilogram). In the generalized stiffness used to calculate the torsional acceleration, the frequency equals the 0,85× T. Therefore, the stiffness value differs from the one used to calculate the along-wind and across-wind calculations. The damping value used in the calculations is taken as 0.01 (1.0%) (Saiful Islam et al. 1990).

$$A_D(Z) = C_D(Z)\frac{U_H^{2.74}}{K_D^{0.37} \times \zeta^{0.5} \times M_D^{0.63}} \tag{25}$$

$$A_L(Z) = C_L(Z)\frac{U_H^{3.54}}{K_D^{0.77} \times \zeta^{0.5} \times M_L^{0.23}} \tag{26}$$

$$A_\theta(Z) = C_\theta(Z)\frac{U_H^{1.88}}{K_\theta^{-0.06} \times \zeta^{0.5} \times M_\theta^{1.06}}, \frac{N_\theta B}{U_H} \leq 0{,}25 \tag{27a}$$

$$A_\theta(Z) = C_\theta(Z)\frac{U_H^{2.76}}{K_\theta^{0.38} \times \zeta^{0.5} \times M_\theta^{0.62}}, \frac{N_\theta B}{U_H} > 0{,}25 \tag{27b}$$

$A_D(Z),\ A_L(Z),\ A_\theta(Z)$: along-wind, across-wind, and torsional RMS acceleration
ζ: damping ratio

After calculating each acceleration value, Eq. 28 (61) was used to find the RMS acceleration value. The B used here likewise refers to the side length of the building in square form, but in this formula, this value should be taken in feet.

$$A_R = (A_D^2 + A_L^2 + \left(B/\sqrt{2} \times A_\theta\right)^2)^{0.5} \tag{28}$$

A_R: resultant RMS acceleration
B: plan dimension (meters)

Ultimately, comparing building motions induced by wind loads with specified limit values provides valuable information about the dynamic behavior of structures under different conditions. Applying the methodology outlined in this study, the wind loads, periods, and acceleration values for hypothetical hospital buildings were calculated. The aim was to examine the complex bond between building height, density, wind speed, and structural response, highlighting the importance of considering these factors in design and safety considerations.

CHAPTER 4

RESULTS

The current chapter presents the results obtained from our calculations. From the entire set of calculations here, this chapter focuses on the critical cases. The calculations are organized and presented in two parts: wind load comparisons and building motion comparisons. The results of the wind calculations are presented comparatively for EN1991-1 and ASCE 7-22 and are analyzed separately for each surface: Windward Wall, Leeward Wall, Side Wall, and Roof Pressures. Then, root mean square values presented based on the pressures obtained from these calculations and presented in comparison with the limit values given in the literature.

4.1. Results of Wind Calculations

Many studies examine the interrelationship of international codes due to globalization in the construction sector (Kasperski 1996; Zhou et al. 2002; Kasperski 2009; Kwon and Kareem 2013; Stathopoulos and Alrawashdeh 2020). As a result of globalization, the work of international teams, especially in large and complex building types such as hospital structures, has made it essential to analyze the differences in various standards developed by countries. To this aim, the wind calculations conducted within this thesis consider two different approaches.

As mentioned earlier in Table 3.6 (39), different codes treat the impact of environmental considerations on wind exposure differently. In this context, the first step in analyzing the calculations was to compare the peak velocity pressure values before multiplying them by the surface coefficients. As analyzed in detail in Chapter 3, according to EN1991-1, the parameters affecting the peak velocity are height exposure category, air density, and speed factors. On the other hand, ASCE 7-22 interdepends peak velocity on wind directionality, topography, ground elevation, basic wind speed, and velocity pressure exposure (ASCE 2022). Accordingly, to compare the results of peak velocity calculations, peak velocity was compared in m/s. The ASCE 7 calculation used the equation representing the result in m/s for the peak velocity and expressed as Equation 12 in the third section. In addition, the velocity data used for this comparison was taken as 10-minute average velocity values and similarly converted according to Eq. 17, given in the third chapter. Moreover, comparisons were made based on the speed and height values to analyze the environmental assumptions made by both codes.

As a result of our comparisons in Exposure D according to ASCE 7-22 (V=27 m/s) and Terrain Category 0 according to EN1991-1 (V=27 m/s), as shown in Figure 4.1b, EN1991-1 exhibits higher peak velocity pressures. Additionally, when the relationship between the velocity and peak velocity pressure is examined, it is observed that EN1991-1 similarly gives higher values and the differences between the codes increase as the speed increases. Consequently, as the values become more critical, the concordance among the codes diminishes.

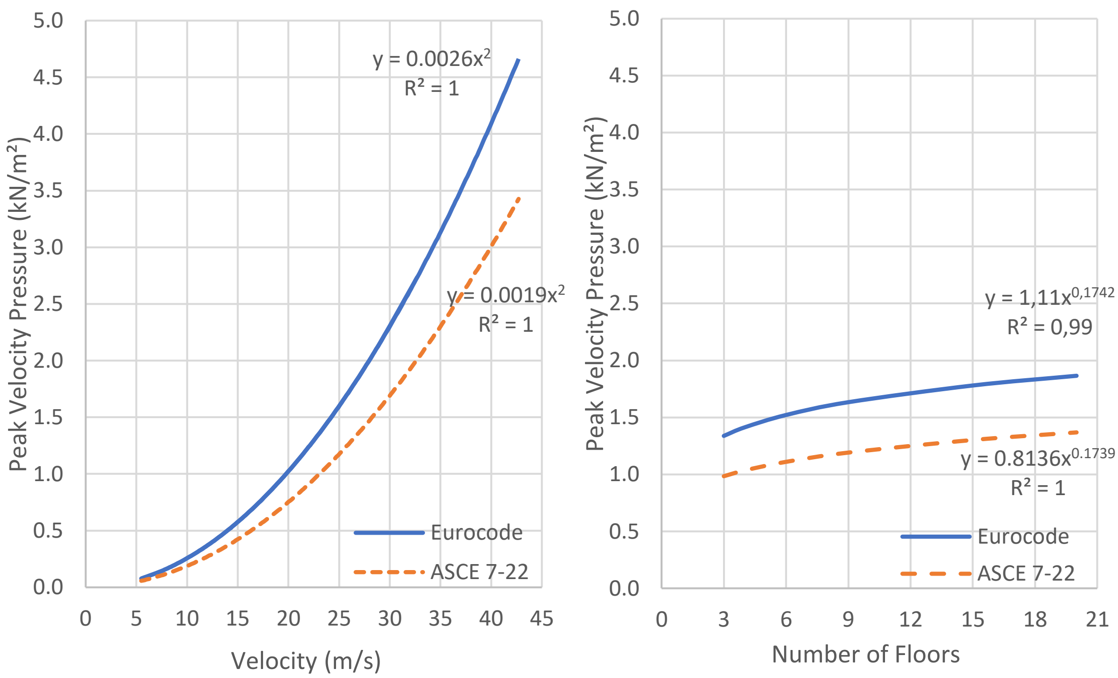


Figure 4.1. a) Peak Velocity Pressure-Velocity b) Peak Velocity Pressure-Number of Floors at V= 27 m/s

Furthermore, when the change according to height due to different environmental factors is analyzed, it is observed that the change is different for each exposure. Accordingly, the height-peak velocity analysis for Exposure B and Terrain Category II and the height-peak velocity analysis for Exposure C and Terrain Category IV are given in Figures 4.2a and 4.2b. Thus, both codes give the closest results, gathered at the conditions with the least wind load and relatively mild environmental factors. This can be attributed to hypothetical distinctions among codes that arise from environmental factors.

In addition to the arguments given, it is essential to note that the calculations at this stage are intermediate steps. Both codes multiply the peak velocity pressure values by different coefficients. In this context, examining the intermediate step aims to analyze the differences in approaches between the codes.

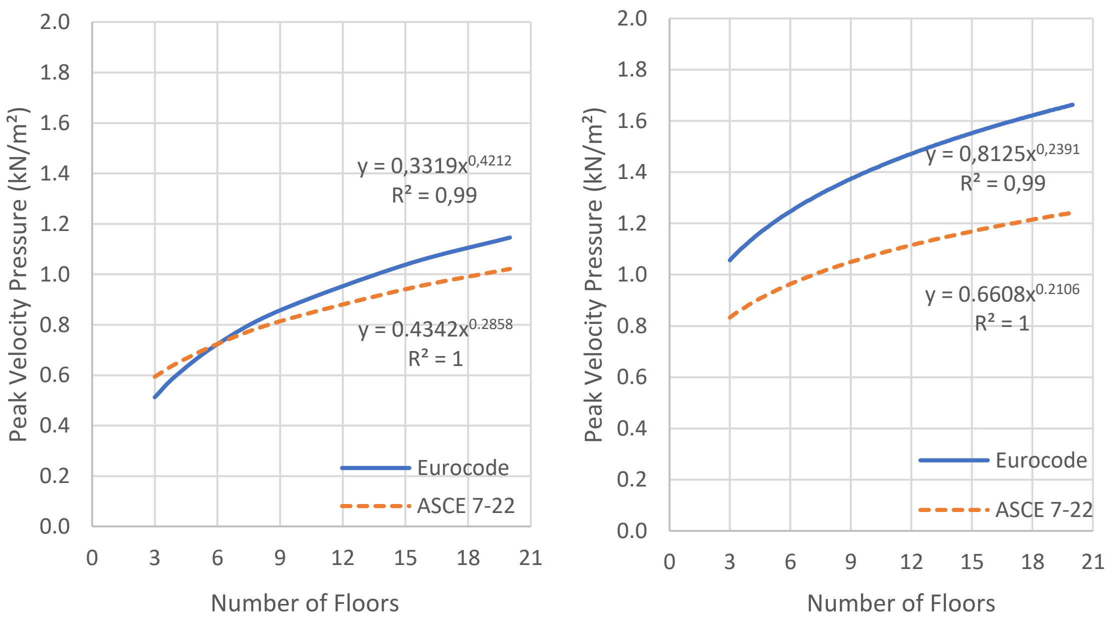
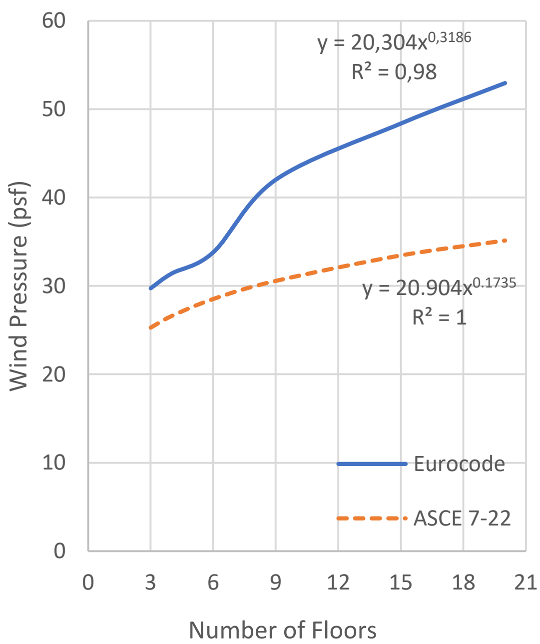


Figure 4.2. Peak Velocity Pressure Comparison for a) Exposure B, b) Exposure C

4.1.1. Windward Wall Pressures

Windward wall refers to the face of the building perpendicular to the wind direction as defined in ASCE 7-22, while the same building face is designated with the letter “D” by EN1991-1. In calculating, the coefficient taken for this face is the same for each aspect ratio value according to Table 3.10 (49) in the direction procedure given in ASCE 7-22. Accordingly, the equivalent pressure on this face is the same for buildings of the same height in the previously determined geometries and the building types exposed to the same environmental factors. However, in EN1991-1, although the coefficients specified for the face designated as D are taken as +0.8 for values above 0.25 depending on the height / long side ratios similar to ASCE 7-22, different results are obtained depending on the internal pressure calculations. Accordingly, it is observed that the calculated data are diverging from each other, especially for the x orientation (Figure 4.3a, 58). In addition to those mentioned above, when the differences between ASCE 7-22 and EN1991-1 in the y directions of the buildings are examined, it is seen that the values for the two codes are closer (Figure 4.3b, 58). However, when analyzed for each geometric type, it is observed that ASCE 7-22 gives safer results after the 19th floor in the 1y geometry with single corridor plan type, while this value is 6 for the 3y model with square form (Fig. 4.4, 67). The mentioned Type 1 corresponds to the single corridor plan type as detailed in Chapter 3. Type 2 refers to the racetrack, and type 3 refers to the Compact Square. The x and y in each type indicate the wind direction acting on these geometries. X denotes that the wind acts from the short side and y from the long side. In the examination of the variances among distinct geometries, the most significant disparities were noted between types 1 and 3, which are presented below.



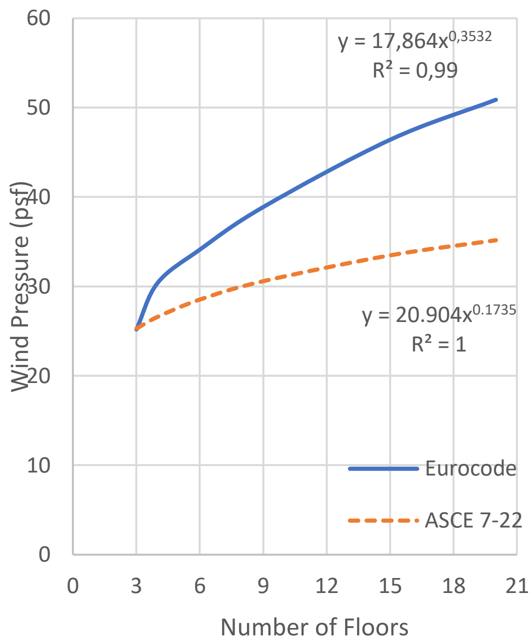


Figure 4. 3. Windward Wall Pressures for a) 1x b) 3x

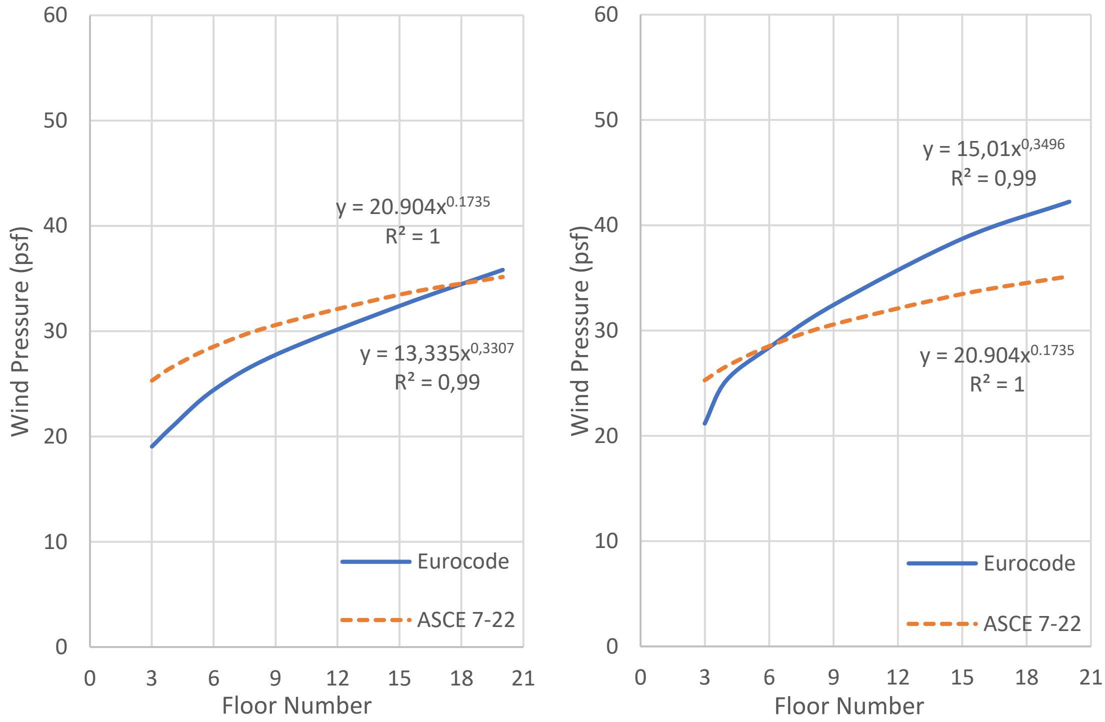
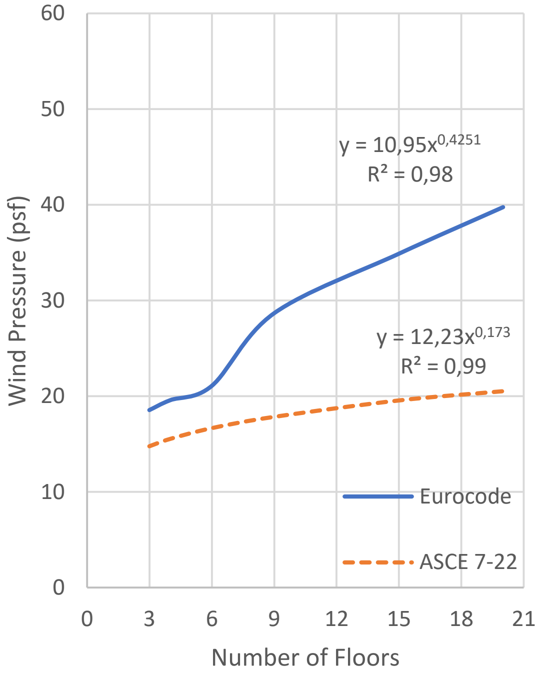


Figure 4.4. Windward Wall Pressures a) 1y b) 3y

4.1.2. Leeward Wall Pressures

Leeward wall refers to the area that can be characterized as the rear face parallel to the area where wind loads act. In this region, the manifestation of suction forces is observed due to the characteristics of wind pressures. While this area is referred to as the Leeward wall in ASCE 7-22, it is named with the letter "E" by EN1991-1. Unlike other building faces, according to the Directionality procedure in ASCE 7-22, different coefficient values are prescribed for this face depending on the aspect ratio (L/B). Accordingly, when the story-wind pressure variation is examined for a building model in the Exposure D category with 27 m/s 10-minute average velocity, the maximum difference is observed in different orientations for geometry type 1 (Figure 4.5, 60).



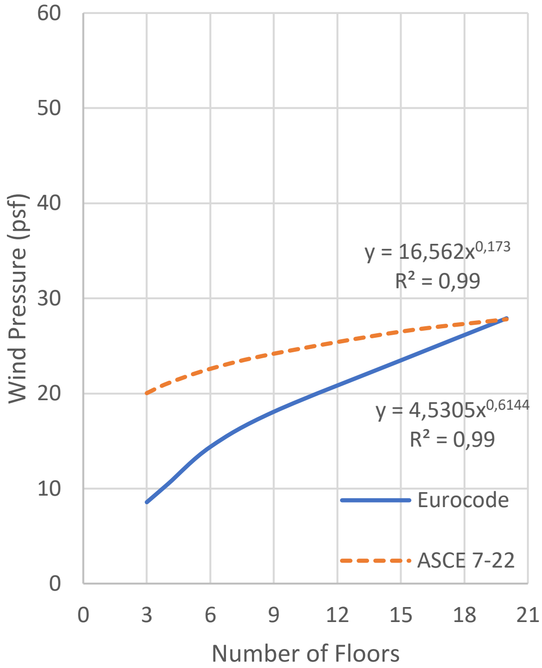


Figure 4.5. ASCE 7-22 -EN1991-1 Comparison for a) 1x b) 1y

Moreover, as delineated in the supplementary figures A.1 and A.2 within appendix A, analogous data sets were procured for geometries 2 and 3 when analyzed in the x-orientation. Nonetheless, upon evaluation of the metrics provided for both standards, it is observed that ASCE 7-22 exhibits a higher margin of safety for structures encompassing a lesser number of stories. Conversely, EN1991-1 demonstrates a higher level of safety from the fourth story for Geometry 2 and the sixth story for Geometry 3.

In addition to the given data, as shown in figures 4.6a and 4.6b, similarly in the y-orientation, the data on which code is safer varies depending on the number of building floors. For a building with 27 m/s 10-minute average velocity and type D exposure, this value changes at the 9th floor for a building with an aspect ratio of 2.56, while for a square building, this value changes at the 13th floor. The story height used when specifying the number of stories mentioned above is 3 m. In cases where the story height is different, this value will vary depending on the total height value, not the number of floors.

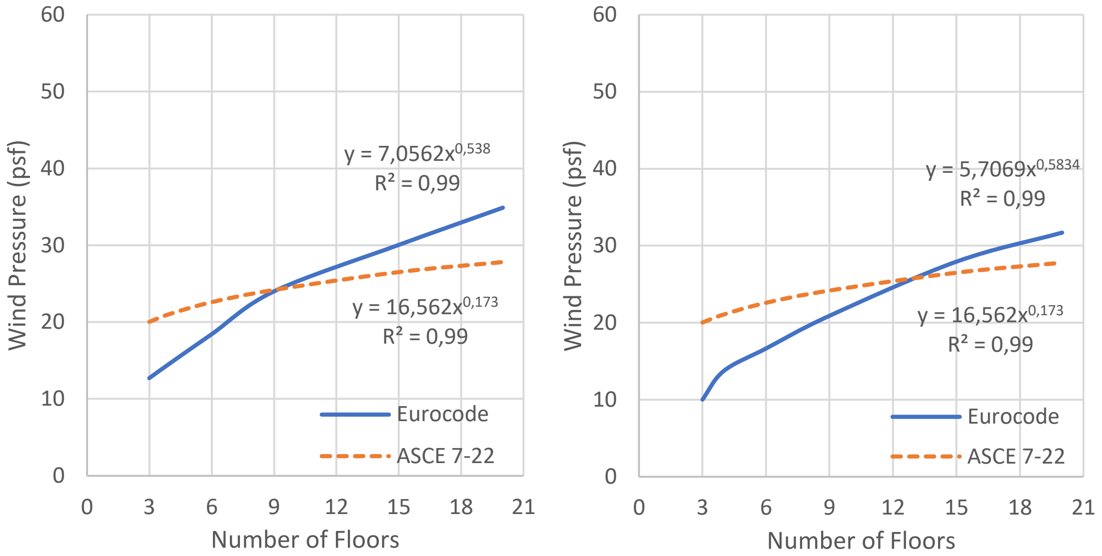


Figure 4.6. ASCE 7-22 -EN1991-1 Comparison for a) 2y b) 3y

Similarly, when the calculations in different orientations for both codes are considered separately, as expected, the most significant difference between the pressures acting on the leeward wall in x and y orientations is observed for the single corridor type called Type 1. Type 1 has an aspect ratio of 4.09 and has the largest aspect ratio among the identified types. However, although there is a gap between aspect ratios, the intersections identified for type 2 and type 3 are more similar than for type 1. For type 1, the point where the results given by EN1991-1 and ASCE 7-22 are the same is at the 19th-floor levels, while when type 2 and 3 are compared, it is seen that the intersection points are 9 and 13.

4.1.3. Side Wall Pressures

The term "sidewall" pertains to the lateral facades of a structure, as defined in ASCE 7-22, which are oriented parallel to the prevailing wind direction. In addition, while ASCE 7-22 examines these surfaces as one, EN1991-1 divides these surfaces into three. These surfaces are referred to by EN1991-1 as A, B, and C. The width of these three surfaces is determined by the value equal to the smaller of b or 2h, called "*e*" in the code. Furthermore, depending on the calculated *e* number, which zones are present, and their areas of influence are determined. The wind pressures of these regions are determined according to the coefficients specified in EN1991-1. Accordingly, the region with the highest pressure is region A. The width of this region's influence area is specified as *e/5*. Therefore, if the length of the sidewall is greater than *e/5*, the code defines the length of the area affected by region B up to a value e, and the area outside this area is called region C. In the light of the provided information, the comparison between the zones and wind pressures as delineated by the EN1991-1 and ASCE 7-22 was enhanced by utilizing a weighted average based on the areas of the zones specified by the EN1991-1. In addition to the calculation basics stated for EN1991-1, the ASCE 7-22 Directionality procedure gives the same coefficient for each L/B ratio; therefore, the sidewall wind pressures for each pre-determined geometric form are the same. Accordingly, in the comparisons made, examining the differences between the exact value given by ASCE 7-22 and the values prescribed by EN1991-1 is essential.

Moreover, the maximal discrepancy in the x and y coordinates is predominantly noted in type 1 (Figure 4.7, 62). As shown in Figures 4.7a and 4.7b, the pressure in the x direction, is relatively higher than the sidewall wind pressure calculated according to ASCE 7-22. On the other hand, in the y-direction analysis, it is seen that the values calculated for the two codes are relatively more compatible with each other. Moreover, in the calculations made in the y direction, the data of which code gives safer results after the 11th floor for type 1 varies, as seen in the Leeward wall. Consequently, similar relationships between pressures for Type 1 are observed for the other types, with relatively minor differences, as indicated in Appendix A (A.7- A.10, 112-113).

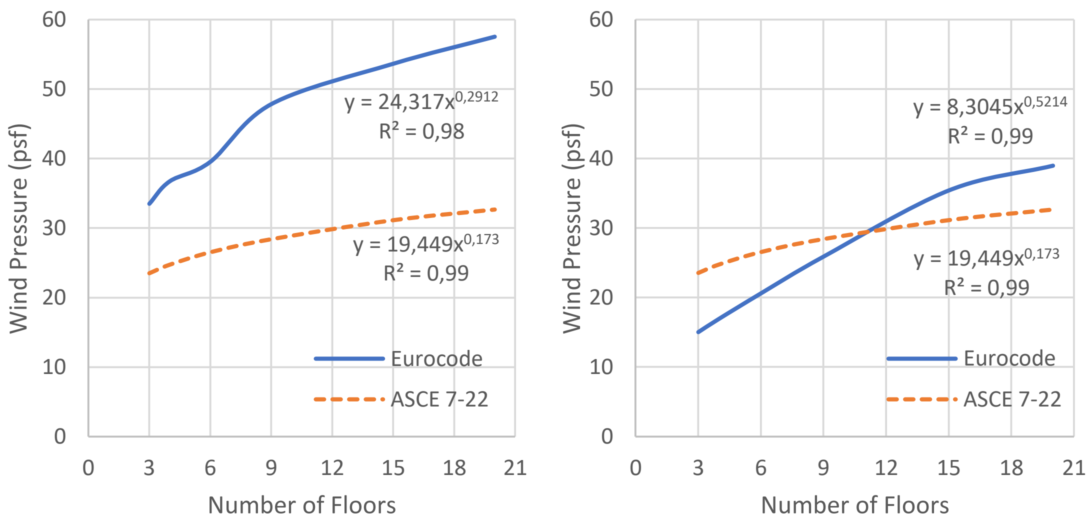


Figure 4.7. ASCE 7-22 -EN1991-1 Comparison for a) 1x b) 1y

4.1.4. Roof Pressures

Within EN1991-1, many roof types have been examined, namely roof types including flat, mono-pitched, duo-pitched, hipped, and multi-span. Accordingly, four widely used types of roofs are analyzed within this study; flat, mono-pitched, mono-pitched, duo-pitched, and hipped roofs (Figure 4.8, 63). Except for the flat roof, three slopes of 5, 30, and 60 were examined for each roof type. In EN1991-1 depending on the types of these roof types, different zoning is used, and different coefficients are given for different roof slopes. Furthermore, the most critical and excessive loads on the roof occur at the corners on the side of the wind, defined as the F zone by EN1991-1.

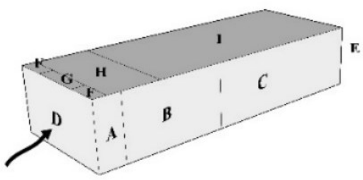
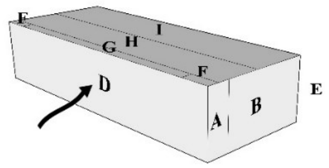
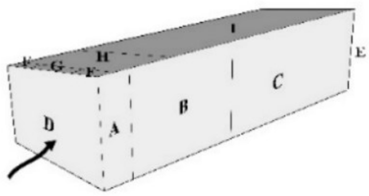
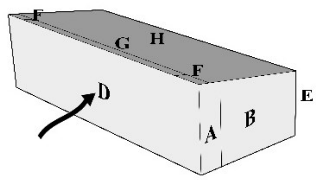
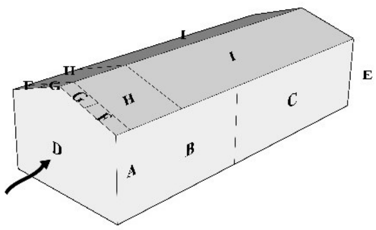
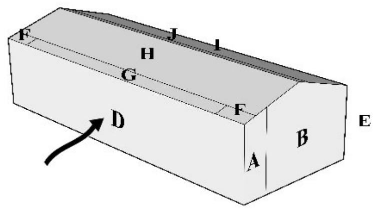
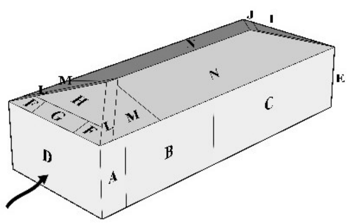
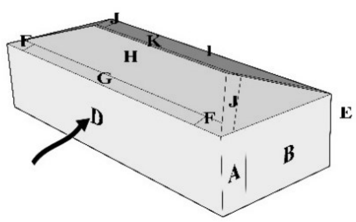
Roof Type	Direction x	Direction y
Flat Roof		
Monopitched Roof		
Duopitched Roof		
Hipped Roof		

Figure 4.8. Roof Type and Zoning

Accordingly, the F zone, which is typical for each roof type and has a critical value, is analyzed. The forces that occur in this region are generally suction forces. Therefore, the analysis of these zone and the wind forces is essential for the roof covering and joint detail choices (Lee et al. 2013). When examined, this region has a length of e/4 at the edge perpendicular to the wind direction and *e/10* at the edge parallel to the wind direction. As stated in the side wall results, the value of *e* is equal to the smaller of 2h or b (the length of the edge of the building parallel to the wind direction).

As illustrated in Figure 4.9, the hipped roof configuration consistently results in the most favorable, lowest, pressure values among the various roof types examined. The information presented in Figure 4.9 pertains to Building Type 1x, characterized by a lateral dimension of 86×21 meters, a detailed exposition of which is provided in Chapter 3. Furthermore, the dataset presupposes that the structure is subjected to exposure D, encompassing maximum wind pressure values. It is imperative to highlight that within the scope of the investigation focusing on various roof types and inclinations pertinent to the specified region, it was determined that exclusively the hipped roof variant, identified as 4c, exhibiting a slope of 60 degrees, yielded positive pressure values. In addition, the same values were obtained for the building types, with the height and aspect values determined for the roof types with 30 and 60-degree slopes for the roof model 3, which were defined as duo pitched by EN1991-1.

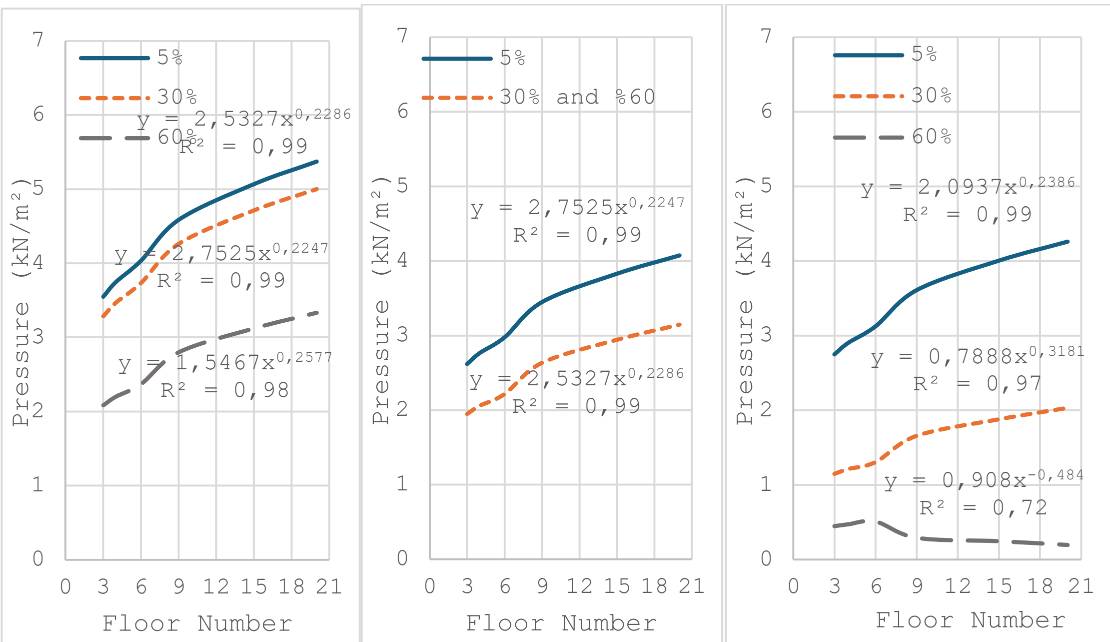


Figure 4.9. Number of Floor- Peak Velocity Pressure at Zone F for a) Mono Pitched Roof b) Duo Pitched Roof c) Hipped Roof

Since roof type selection, coating selection, and details are made in line with the architect's design decisions, the loads to which the roof is subjected and their relationship with roof selection and materials must become information used by architects in general terms. Moreover, damage to the building envelope can lead to more significant damage later on when these areas are exposed to wind pressures or water-borne damage due to the loss of integrity of the building elements (Boughton et al. 2011).

In this sense, fragility analyses were conducted to assess more deeply the implications of this review for the architect as design inputs. Fragility is defined as the probability of exceeding a specific state of damage (Abdelhady et al. 2022). Therefore, fragility curves are tools used to assess the risk of exceeding a certain damage or a limit. These fragility curves are used to determine the probability of exceeding limit values set by different parameters. They can be used as auxiliary tools in the design phase. One of the steps required for this assessment is to determine the limits that will be examined for the probability of exceedance, which are referred to as damage states. Accordingly, fragility curves can determine damage probabilities at the level of individual elements (Gavanski et al. 2014) and within a broader systemic framework (Dong and Li 2016).

In this study, fragility curves were developed to understand the link between roof selection and damage probability. In this context, analyses for each roof type were used. These analyses were performed for the F zone, which is subjected to the highest pressures. Since the main purpose of the brittleness analysis is to understand the effect of roof morphology, the analysis is based on the fracture limit of a single material. The sandwich panel was chosen as the material for the roof covering, and the fragility analysis of this specific material is detailed in Figure 4.10 (65). The breaking point of this material was taken as 3.25 kPa (Abdelhady et al. 2022) and analyzed separately for each roof type and slope. In light of the results, as seen in Figure 4.10 (65), it is observed that in cases where the roof slope is 5 degrees, regardless of the roof type, the material fragility exhibits similar vulnerabilities to the flat roof. The structures featuring hipped roofs exhibit the minimal material fragility. Furthermore, within the range of slopes assessed, it was determined that roofs possessing a 30-degree incline demonstrated the most reduced fragility indices. Since the wind pressure coefficients of the roof types Monopitch and Duopitch in two different directions are highly different, only the data in the critical direction is used for the fragility analysis.

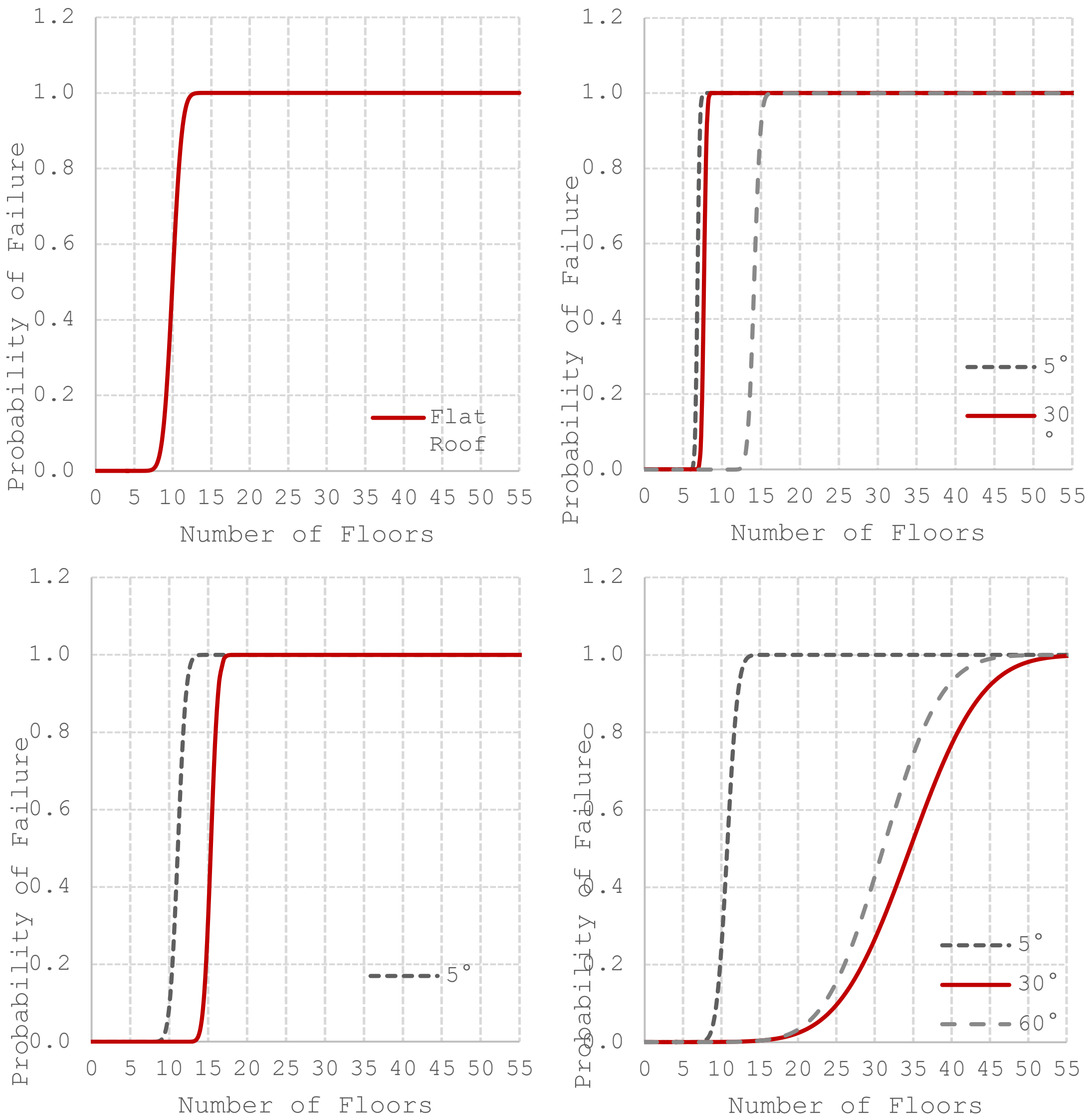


Figure 4.10. Roof fragility curves a) Flat Roof b) Monopitch roof b) Duopitch Roof c)Hipped Roof

4.2. Results of Building Motion Calculations

In an effort to examine the effects of wind speed more efficiently, as the second phase of the study, the effects of building motions caused by wind loads and limits stated in the literature were compared. In making these assessments, the values considered as thresholds for human satisfaction based on the criteria mentioned in Chapter 2 are utilized. Accordingly, results are compared with the equipment and imaging device thresholds mentioned in the literature. While presenting the data obtained, the first examinations for each building type were presented separately. Then, the comparative examinations of the data were obtained at the end of the section.

Regarding the impact of wind, it is imperative to consider the damage inflicted upon structures and investigate the motion behavior induced by wind forces. Consequently, in addition to adhering to the safety mandates pertaining to wind forces, the criteria for serviceability are deemed of substantial significance (Kwok 2013). As mentioned in Chapter 2, wind induced building motion can influence the occupants' daily activities, overall satisfaction and well-being and extended exposure to these vibrations can lead to discomfort, impair focus on tasks, and possibly induce headaches, nausea, and dizziness (Kwok 2009).

For the purpose of comparison, the obtained results were evaluated against the limit values specified for commercial buildings as defined by Griff (Griffis 1993), as presented in Table 4.1 (42-43). How applicable these limits are for hospital buildings and the requirements of hospital buildings themselves will be discussed in the discussion section.

Table 4.1. Root-Mean-Square (RMS) Acceleration Limits (Griffis 1993)

Occupancy Type	**Peak Acceleration (Milli-g)**	**Root-mean-square (RMS) Acceleration (Milli-g)**		
		1≤ T < 4	**4≤ T < 10**	**T ≥ 10**
Commercial	15-27	3.75 - 6.75	4.00 - 7.20	4.29 - 7.71
Residential	10-20	2.50 – 5.00	2.67 – 5.33	2.86 – 5.71

4.2.1. Type 1: Single Corridor

In the calculation of root mean square (RMS) acceleration for each typology, the wind pressures acting on the windward front obtained from EN1991-1 and ASCE 7-22 were taken in psf. These analyses cannot be performed for different orientations for ASCE

7-22 because ASCE 7-22 does not give different surface pressure coefficients for different L/B ratios when defining the Windward wall pressure. Therefore, according to ASCE 7-22, the pressures on this surface are the same for both orientations.

The single corridor plan type, Type 1, presents the most efficient area-patient ratio. Hence, this plan typology exhibits the most minor loss in circulation spaces. On the other hand, it has a relatively high aspect ratio of 4,09 compared to other hypothetical types. Figure 4.11 shows the variation of the RMS acceleration (RMS ACC) values at different floor numbers for type 1. It can be seen from the graph that the calculations based on ASCE 7-22 are giving higher values. While the limit value for the same building is exceeded at the 13th-floor level according to the ASCE code, it is observed that for EN1991-1 the limit value has reached the limit at the 30th-floor level. As per our directional analysis of the single corridor, it has been observed that the RMS accelerations are comparatively more critical when the windward elevation is the long front as opposed to the other scenario where the windward elevation is shorter (Figure 4.11, 68).

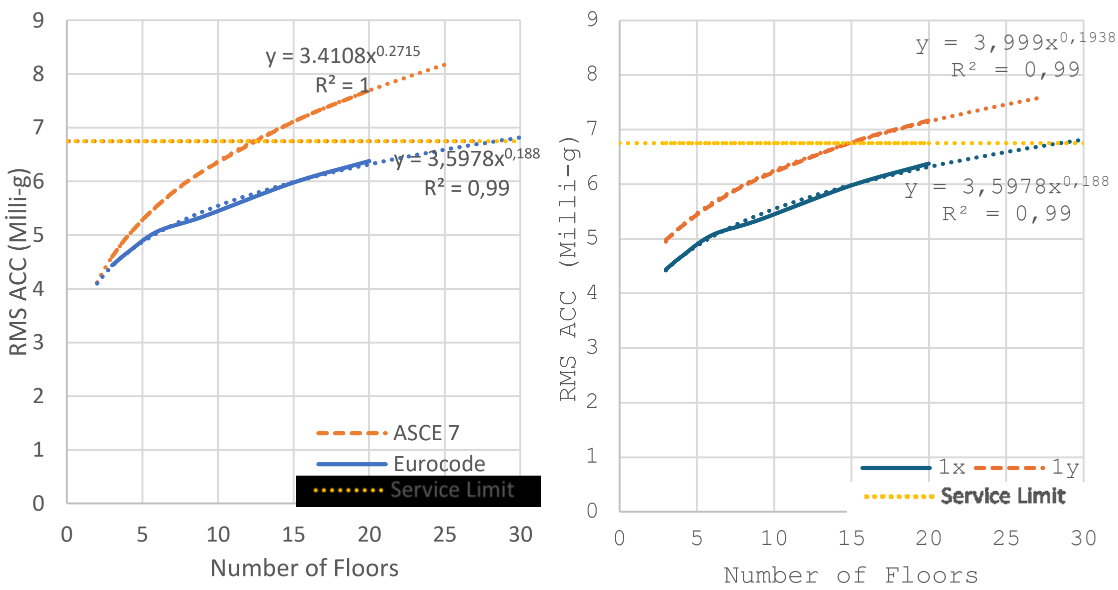


Figure 4.11. a) Floor Number-RMS ACC Relationship, b) Number of Floors-Directionality Relationship for Type 1 (EN1991-1)

According to EN1991-1 calculations, as a result of the two-way examination for the same building type, it is seen that the building in the y-orientation reaches the limit value on the 15th floor. In contrast, in the x-orientation, it reaches the limit value at approximately the 30th floor. As a result of the calculations, as expected, it is observed that the hypothetical building with 20th floors reached the critical threshold limits at the slowest wind velocities. Furthermore, the results show that the calculations made using ASCE 7-22's directions give higher RMS acceleration results (Figure 4.12, 69). Based on the calculations derived from ASCE 7 and EN1991-1, the limit values for wind speed are estimated to reach approximately 25 m/s and 27 m/s, respectively. Similarly, figure 4.12 for the directional factors based on EN1991-1 calculations shows that for the circumstance where the wind acts on the longer side, circumstance 1y, the limit values are reached at lower wind speed. Accordingly, since the building is designed based on the critical wind loads acting in these two directions, the wind value acting in the y direction is used as the determining value for this building.

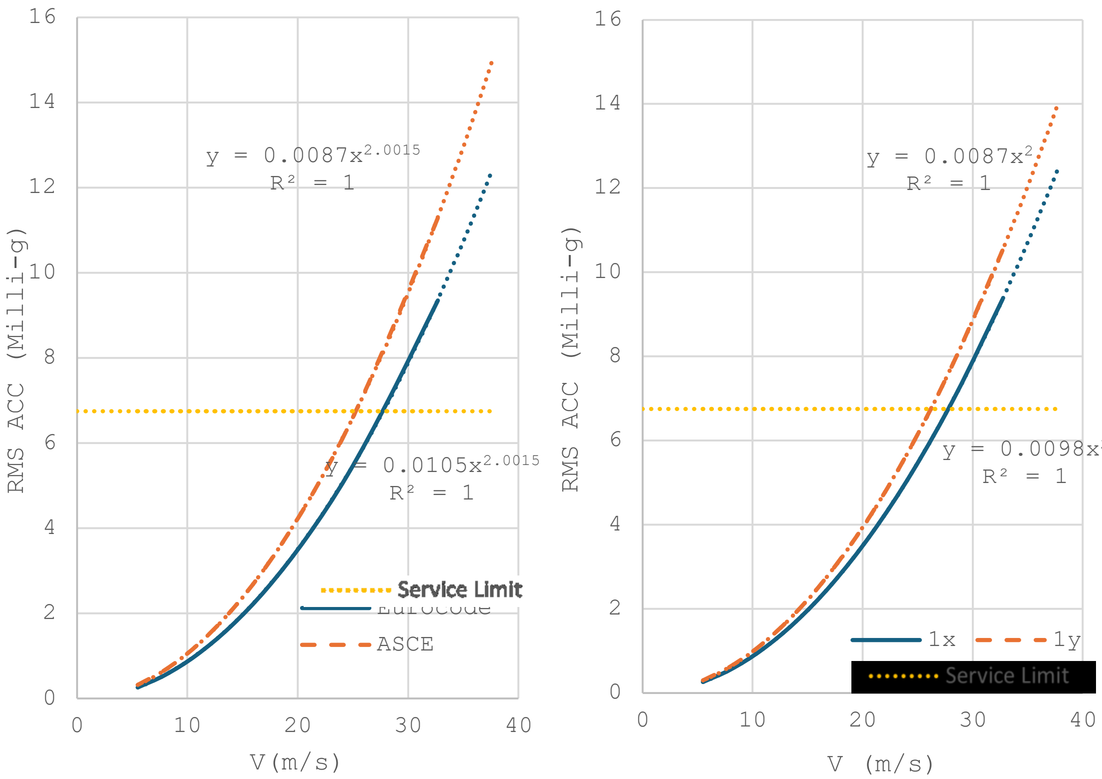


Figure 4.12. a) Velocity Based Code Comparison b) Velocity- Directionality Comparison for Type 1 (EN1991-1)

4.2.2. Type 2: Racetrack

The racetrack plan, type 2, has the highest area of the three hypothetical building types. However, it is the type with the highest area-to-patient ratio due to the logic of encircling the central service line with the double corridor used in the design; the space requirement for circulation is higher than the other types. Consequently, the racetrack type accommodates two nursing units. Unlike the Single Corridor, it can be seen as advantageous in terms of the multiplicity and accessibility of service venues. On the other hand, the aspect ratio is less, at 2.56, compared to the single corridor. In addition, similar to the first type, it was observed that the values calculated with ASCE 7-22 remained on the safer side. Furthermore, when the wind acts perpendicular to the long side, in the y-orientation, it is observed that the root mean square acceleration values of the building reach critical levels on fewer floors (Figure 4.13, 69). Additionally, the outcomes of the directionality analyses exhibit that the building's reaction to wind is similar in both directions, given an aspect ratio of 2.56. Nonetheless, it is more prominent when the wind influences the building along its longitudinal axis.

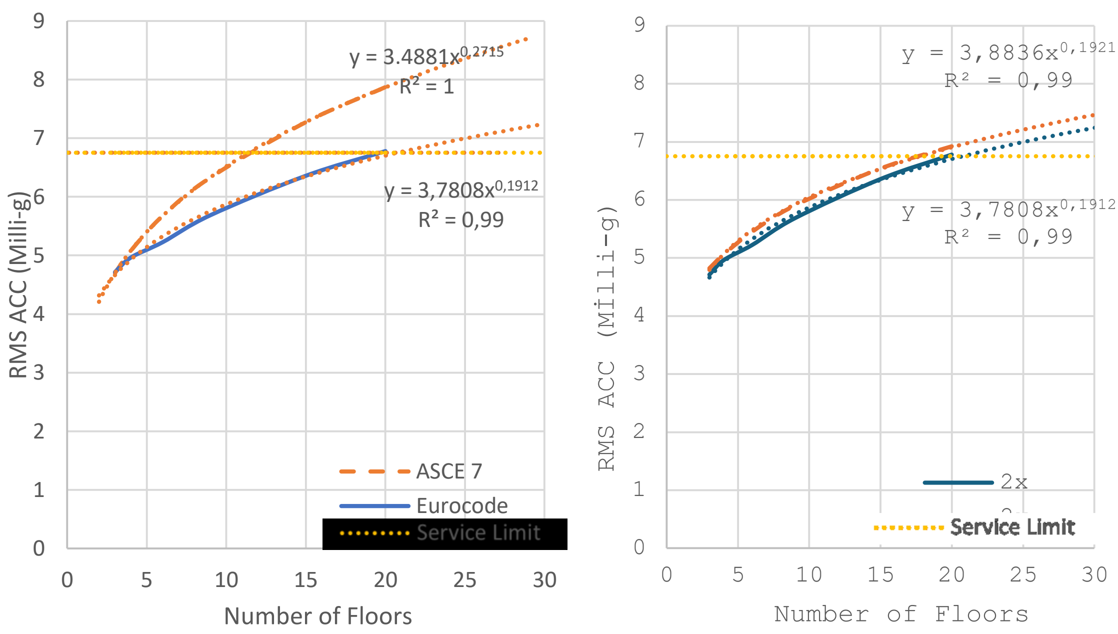


Figure 4.13. a) Floor Number-Based Code Comparison b) Velocity- Directionality Comparison for Type 2 (EN1991-1)

When the relationship between the racetrack type and the speed variability examined, it is observed that the root mean square (RMS) values related to wind pressures obtained with ASCE 7-22 reach limit values at lower speeds compared to EN1991-1 (Figure 4.14, 70). Upon examining the correlation between various orientations, it is apparent that the findings obtained for this category are remarkably similar (Figure 4.14, 70).

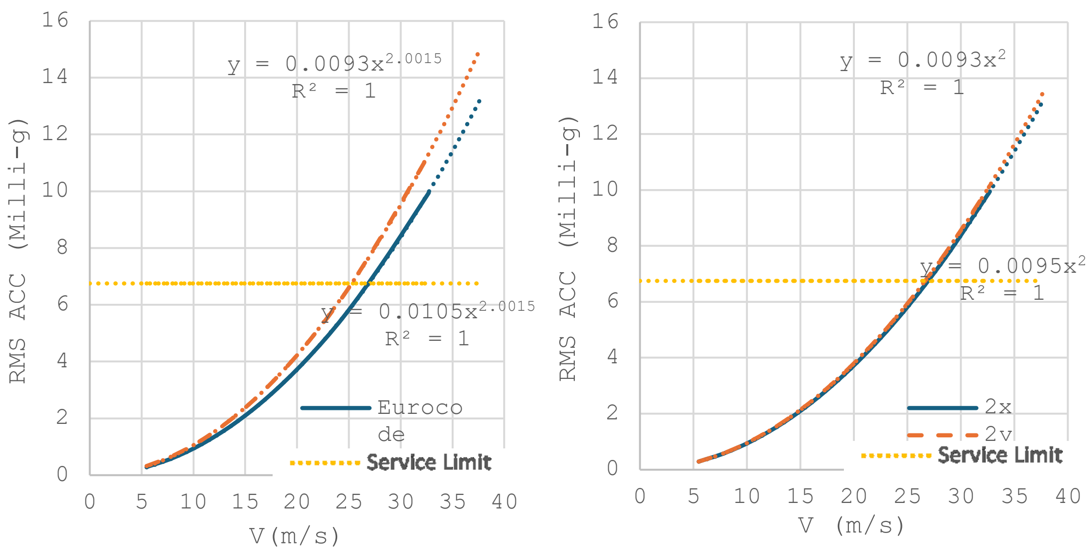


Figure 4.14. a) Velocity Based Code Comparison b) Velocity- Directionality Comparison for Type 2 (EN1991-1)

4.2.3. Type 3: Compact Square

The square-shaped plan type has the most minor area among the generalizations that have been proposed. This plan type also has the lowest number of patient beds. In addition, the area-patient ratio is 27.45, in the middle of the other two proposed generalizations. The equality of its side lengths characterizes this building type. However, the windows on either side do not share the exact dimensions. This is due to a corridor extending to one end, providing access to the rooms.

Concerning the directionality analyses, minor differences were observed due to the different circulation, thus opening locations. Furthermore, although similar relationships are examined in the relationship with building height (Figure 4.15a, 71) in the ASCE and EN1991-1 comparisons, it is observed that the values for this type give more similar results instead of being separated for increasing speeds. Therefore, as shown in Figure 4.15b, both codes show similar root mean square values for the building type with an aspect ratio of 1 depending on the velocity changes.

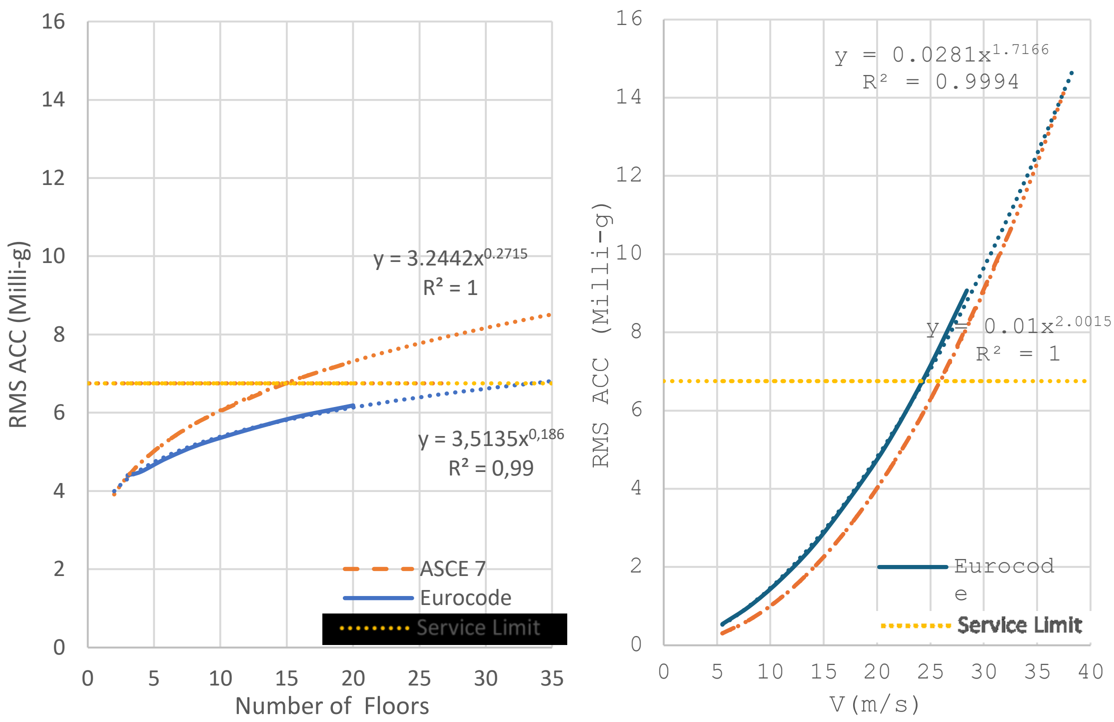


Figure 4.15. a) Floor Number-Based Code Comparison b) Velocity- Directionality Comparison for Type 3 (EN1991-1)

4.2.4. Compared Results

Calculations were conducted for each building type at different building levels to examine the RMS acceleration values that differ depending on the different aspect ratios created by the plan solutions. As a result of the calculations where the wind speed is 27 m/s (Figure 4.16, 72), it is observed that the racetrack plan solution, which is expressed with 2x among the building shapes with an aspect ratio of 2.56, reaches the specified limit value in the minimum number of stories. Furthermore, the calculations show that the last building type to pass the limit values is the square form, which is 3x and symbolizes the Compact Square plan type. On the other hand, when the same analysis was performed for the critical direction for each plan type, it was observed that Type 2 (Racetrack) was no longer the fastest to reach the critical values. As can be seen in Figure 4.16, it is observed that the critical value for plan Type 1 (Single Corridor) in the y-orientation reaches the limit values faster than the other types. In addition, while the lowest coefficient reaching the critical value was 20 in the x-direction analysis, this value was 15 in the y-direction analysis. In building type 3, the change in reaching the limit value is due to the window positioning of this building and the internal pressure change caused by this window positioning in different directions.

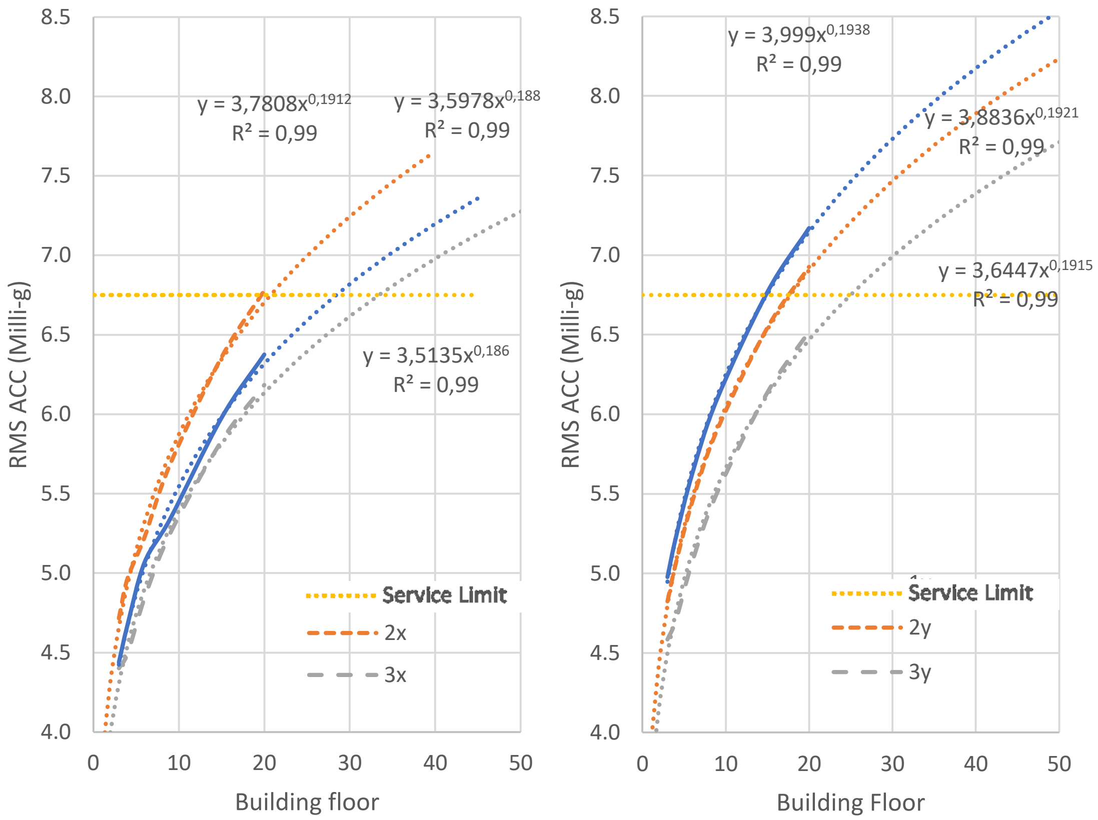


Figure 4.16. Floor Number- Geometry Comparison for EN1991-1 a) Directionality x b) Directionality y

Likewise, comparing these values with the data in the calculations using the ASCE 7 code (Figure 4.17, 73), despite being the most tolerable building type, even the Compact Square (3x) is subject to a limitation of 15 bands for the number of stories.

Furthermore, similar divergences in the calculations for each geometry when comparing ASCE-EN1991-1 values were observed (Figure 4.17, 73).

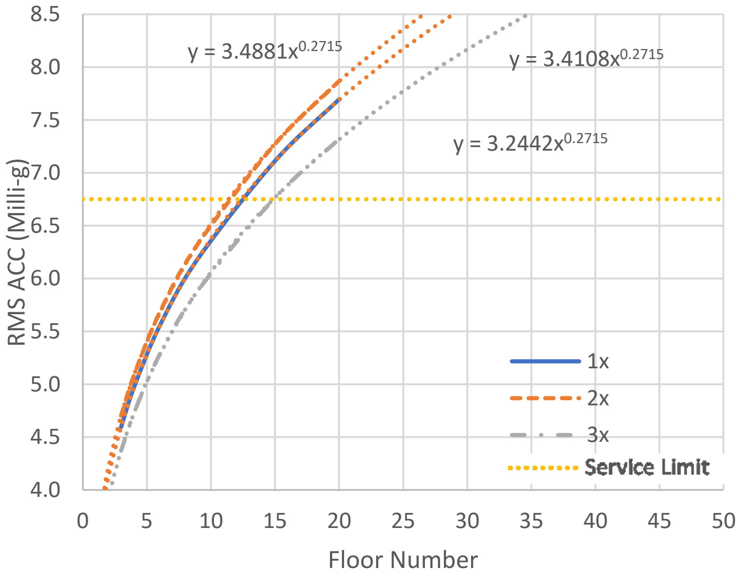


Figure 4.17. Floor Number Geometry Comparison for ASCE 7-22

4.2.5. Motion Perception Fragility

The study undertook an examination centering on the probability of disturbance regarding the perception of wind-induced building motion. This detailed analysis presents the probability of disturbance for wind velocity and floor number for the various architectural layouts outlined in this thesis. This examination gives insights into the average threshold levels at which such disturbance probabilities are customarily surpassed. To conduct a comprehensive analysis of fragility curves, it is imperative to ascertain the values that are delineated as a damage state. The damage statuses used in this analysis, the definitions of these values, and the required limit values (Griffis 1993) are given in Table 4.2 (75). As defined in the table, values between 3.75 and 6.75 are defined as the target range for commercial buildings. In addition, values above this range are defined as damage state two. It should be noted that the values given in this definition are given for commercial buildings. Consequently, their applicability to diverse user groups or the specialized medical apparatus situated within hospital premises remains outside the scope of this initial definition. The suitability of these limit values within the framework of healthcare facilities will be discussed in the discussion section.

Table 4.2. Definition of Damage States (DS)

Damage State	Damage Description	Root Mean Square (RMS) Acceleration (Milli-g)
1	Within the desired range	>3,75
2	Over the limit	>6,75

The fragility curves drawn represent the probability of exceeding the limit values based on the data obtained from the calculations. Figure 4.18 (74) shows exceedance probabilities dependent on Wind Speed properties. The fragility curves in Table 4.2 (74). are plotted for examples with flat roof type and exposure B category according to ASCE. The data used in the velocity-dependent fragility consists of RMS acceleration data at different velocities for data sets with different story numbers. Fragility curves for different building types give the same damage state curves regarding the relationship with velocity. The speed value used here refers to the 10-minute average speed expressed in EN1991-1.

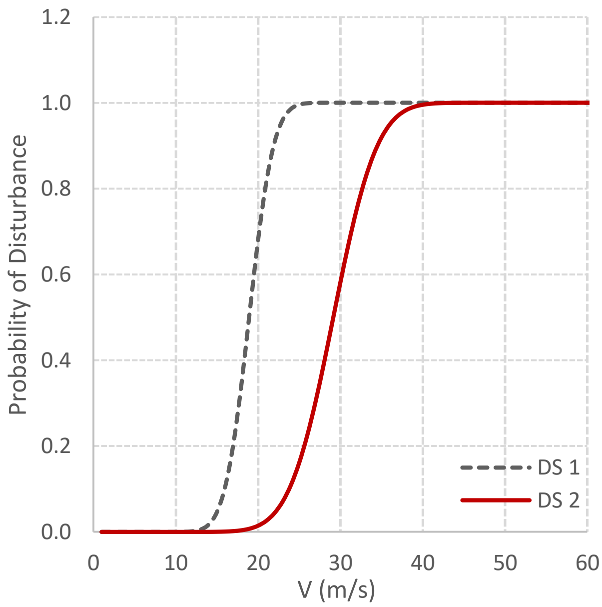


Figure 4.18. Probability of Disturbance Depending on Wind Speed

Data sets with different story heights from each building type were used in the RMS acceleration fragility analysis for the number of building stories. The buildings in the data sets have flat roofs and are B-exposure category buildings according to the criteria specified in ASCE 7-22. Wind with a speed of 27 m/s is taken as a basis for the given fragility curve. This value is the 10-minute average speed value expressed in EN1991-1.

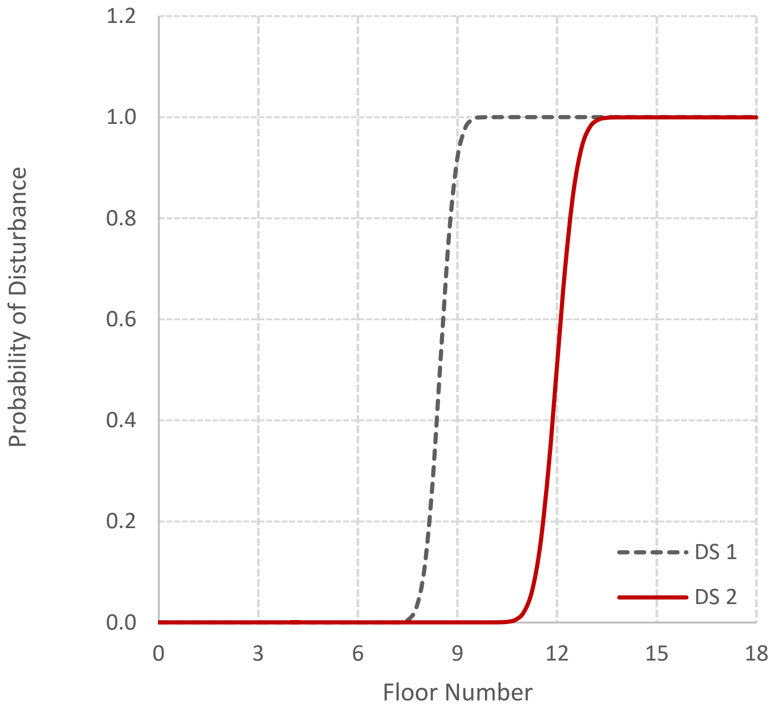


Figure 4.19. Probability of Disturbance Depending on Floor Number

CHAPTER 5

DISCUSSION

This chapter presents a detailed examination of the data derived from calculations presented in Chapter 4. It is structured into four main sections, discussing the size effect, code differences, roof pressures and selection, and the suitability of building motion limits for healthcare facilities. Each chapter discusses different research questions in connection with the obtained results. The chapter aims to provide an analysis building upon foundational calculations and offering actionable insights into architectural design.

5.1. The Effect of Size

The evolution of healthcare facilities over time has been influenced by many factors, including but not limited to the demand for better care, teaching methods, operational changes, and many more. Despite the anticipatory nature of these changes, a discernible trend towards the expansion of healthcare spaces has been observed. Understanding the rationale and implications of this growth plays a vital role in advancing healthcare design. In his research, Latimer et al. (2008) attribute this trend of growth to various factors: changes in operational and patient care models, consumer demand and market competition, patient severity and disease prevalence, technological improvements, and building codes and regulations. They argue that the size of the inpatient floors of these hospitals has increased significantly as the healthcare sector has favored single-bed rooms, minimum spaces for patients are recommended in codes, and the size of patient rooms has become a marketing tool as a parameter of comfort and quality of care (Latimer et al. 2008, 80-82).

Consequently, the expansion of room sizes has necessitated larger circulation areas. Moreover, the rise in technological equipment usage, along with the need for its storage, has further contributed to the enlargement of these spaces. This expansion further complicates the categorization of these facilities. The construction of new hospital facilities is being undertaken on a larger scale in response to the escalating demand for space, coupled with the addition of annex buildings to pre-existing hospital complexes. This expansion in size and complexity of hospital infrastructure presents significant challenges to the optimization of inter-departmental connections and communication, thereby complicating the operational efficiency of healthcare services.

Therefore, categorization becomes crucial in enhancing the design and operational efficiency of infrastructural frameworks. According to Forty (2000), the two most commonly used inputs for architectural classifications are form and function. One of the classifications in terms of form is Prasad and colleagues' (2008) classification of hospital buildings as linked pavilion (finger plan), low-rise multi-courtyard, monoblock, podium and tower, street, atrium, unbundled, campus. However, as Pachilova and Sailer (2015) point out, this categorization is not always possible, mainly because these types are often observed not in isolation but intertwined. In addition, a second approach was proposed by Steadman and Mitchell (1983). In this approach, the authors consider existing complex building types as components, including completed courtyard, rectangular blocks, L, T and U shapes, to examine every possible shape.

This thesis contends with the inherent challenge of classifying such frameworks, particularly within the context of hospital structures, due to their highly varied morphology. The main reason why this issue becomes a challenge in the scope of this thesis is that the types specified for the calculations to be performed have a wide variety of variations within themselves. Therefore, the calculations were limited to the inpatient floor and only adhered to some commonly used design principles in terms of categorization. Thus, in the hypothetical inpatient floor layouts created, except for this principle, nurse rooms, patient room shapes, vertical core cores were kept common. And varying aspect ratios depending on these principles were taken into consideration (Figure 5.1, 78)

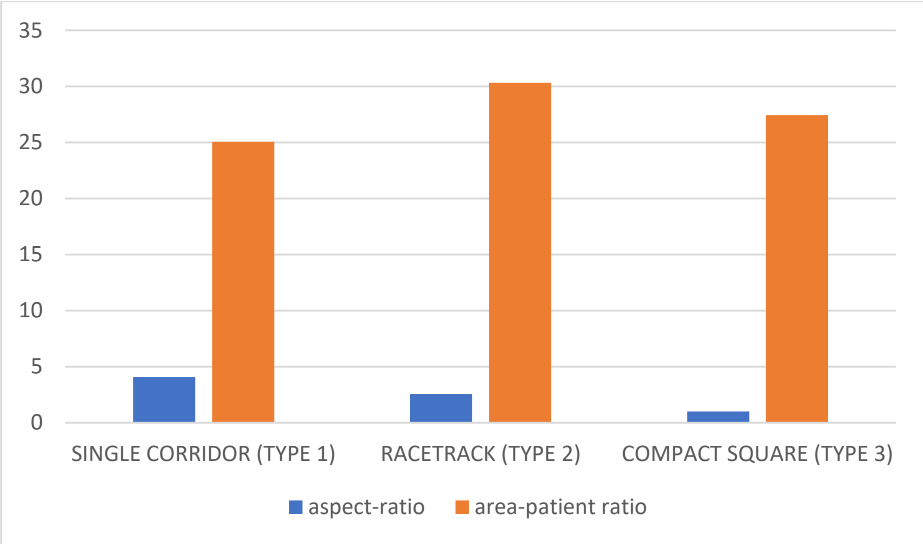


Figure 5.1. Aspect Ratio- Area Patient Ratio for Model Types

There are numerous studies that examine the merits and shortcomings of various morphologies in terms of daylight, air quality, acoustics, external views, walking distances, communication strategies, energy performing, single or multi-bed rooms, nursing unit configurations (Pachilova and Sailer 2015). According to Pachilova and Sailer (2015), the complexity and size of a healthcare facility indirectly effects the quality of care by changing the communication patterns among staff and effecting visual range within the space.

However, the issue discussed in this thesis is the structural effects of this morphological growth in hospitals. As a result of the calculations, it was seen that the different operation decisions taken on the inpatient floors are related to the height of the building and the regional conditions of the wind. Moreover, it was determined that this relationship reaches the limits that can affect human comfort and monitoring equipment.

Accordingly, in Figure 4.16 (72), buildings with different morphologies exhibited different performances in terms of occupant comfort regarding wind-induced building motion. In accordance with the data presented in Figure 4.16 (72), structures characterized by diverse morphological attributes demonstrated varying efficacy in facilitating human comfort in terms of motion perception. The analysis derived from the mentioned figure reveals that Compact Square attained the threshold values on the 25th floor, while Racetrack and Single Corridor reached these values on the 18th and 15th floors, respectively. This indicates that the frequency with which Compact Square approached the limit value was 40% greater than that of Single Corridor, suggesting a significant differential in performance related to human comfort regarding motion perception across the examined building morphologies.

With reference to research questions 1 and 2 (Question 1: "What is the interconnected relation between the morphology of hospital buildings and wind exposure?", Question 2: "What morphological features of hospital layouts are critical concerning the wind exposure?") given Chapter 1, the relationship of hospital structures with wind goes beyond structural dimensions with the increasing size and complexity of these structures. As the mass of the building grows, the traces of its interaction with the wind are likely to be observed not only in the structural integrity of the building but also in its internal functioning and occupant satisfaction. The main morphology-related factors that shape this relationship are height, aspect ratio, and the ratio of height and side lengths. Additionally, the morphology of a building, while being a critical determinant, isn't the sole factor influencing the forces acting upon it. The environmental context—particularly aspects such as wind speed and the density of surrounding buildings— also greatly influences these forces, as expected. As anticipated, areas of high wind speed can exert increased pressure and dynamic forces on structures, necessitating design adaptations to mitigate potential impacts.

5.2. The Impact of Code Differences

In projects as substantial and critical as healthcare facilities, the influence of globalization has led to an increasingly common scenario where individuals with diverse educational backgrounds collaborate within international teams. Therefore, it has become important to develop an understanding on the differences suggested by the national codes to improve communication within these teams. Although these formulations have a similar theoretical foundation, there has been significant variation in the codes and standards' predictions stated in the literature (Lungu et al. 1996; Zhou et al. 2002; Kasperski 2009; Kwon and Kareem 2013; Stathopoulos and Alrawashdeh 2020). These long and comprehensive documents can be challenging for those trying to understand the implicit and explicit concerns outside the field. At the same time, the differences between these documents can be confusing.

Therefore, this section is formulated to answer two research questions, question 3 and question 5 (Question 3: "To what extent are the differences between different wind load calculation codes, what are the reasons behind these differences, and to what extent do they affect working groups involving different stakeholders? ", Question 5: "How does hospital morphology and wind exposure interaction affect the motion perception? What are the given limits? In which cases these limits are exceeded?"). It is significant for teams of architects to understand the effects of wind on the building and consider it among the design inputs that influence the overall organization and composition of masses. To explore the variances among these codes, this section delineates these differences through four analytical frameworks: i) differences in peak velocity pressures, ii) variations stemming from environmental factors, iii) loads exerted on facades, and iv) disparities in root mean square (RMS) accelerations.

i. Peak velocity pressure:

When analyzing the peak velocity pressure, an initial step in the calculations for both codes assessed in this thesis reveals that the factors influencing this value are consistent across both codes. The peak velocity pressure depends on wind speed, the structure's height, and environmental parameters. Regarding the first of these variables, wind speed, ASCE 7-22, and EN1991-1 adopt different approaches (Lungu et al. 1996; Kwon and Kareem 2013). EN1991-1 defines the basic wind velocity as the characteristic 10-minute average wind speed at 10 meters above the ground in rural areas. On the other hand, ASCE 7-22 uses a 3-second gust speed. Formulas for converting these two velocities within this thesis are given in Chapter 3 (Eq. 17, 58).

ii. Variations stemming from environmental factors:

Since the wind speed and building height are kept constant to compare the codes within the scope of the study, the reason for the differences in results is that the assumptions made between the codes depend on the assumptions of environmental influences. Moreover, while EN1991-1 examines the different environmental situations in five categories (Terrain Categories: 0, I, II, III, IV), ASCE 7-22 examines them in three (Exposure Categories: B, C, D). This may prevent the same outputs from being obtained from the calculations because a one-to-one match between these categories is unattainable. Based on the results provided in Chapter 4 (Figures 4.1b, 4.2a, 4.2b, 64-65), it is evident from analyses conducted on structures with the same aspect and opening ratios that the differences identified between codes for the calculated peak velocity pressure values for different exposure categories show variations. Moreover, the mentioned variations exhibit increased severity in contexts subjected to higher wind velocities. One primary cause of these variations stems from the differing approaches to the basic wind speed, resulting in a multiplication difference of 0.67. Additionally, the speed values are squared to compute the peak velocity pressures. The secondary cause of these variations is that EN1991-1 additionally considers the effect of wind turbulence.

iii. Loads exerted on facades:

Upon reviewing the link between height and pressure on various surfaces (as shown in Figures 4.3a, 4.5a and 4.7a, 66-70), apparent inconsistencies were observed within the EN1991-1 computational approach. These inconsistencies mainly appear as sudden changes, which can be traced back to an alteration in the ratio of height to width starting at the seventh floor. This change is due to the combined effect of the number of stories multiplied by the height per story exceeding a specific ratio (0.25) when compared to the width of the surface. As a result, this adjustment leads to changes in both the estimated internal pressures and the relevant coefficients for the surfaces under examination.

Furthermore, while EN1991-1 examines the area in three different sections in the facades called sidewalls, which are located parallel to the surface where wind loads are affected, ASCE 7-22 considers the sidewall as one surface. Therefore, while EN1991-1 suggests a facade where the wind pressures decrease gradually, ASCE 7-22 gives a wall that's effected by a uniform pressure. In addressing this issue and to achieve more consistent results in this study, the calculations for the side surface area within the framework of EN1991-1 utilized a weighted average approach.

iv. Disparities in root mean square (RMS) accelerations:

One of the critical points within the scope of this thesis was to analyze the architectural consequences of different calculated wind loads. In this sense, RMS acceleration due to wind and human comfort examination provides valuable insights into what these calculation variations can mean in architectural terms. During the evaluation of motion-induced human comfort limit, it was observed that both codes exhibit similar behavior depending on the speed factor. For both codes, it was concluded that the theoretical limit stated in the literature (Griffis 1993) were exceeded at similar values of 25 m/s and 27 m/s, respectively. However, differences were observed in the relationships they established with height. For Single Corridor, ASCE 7-22 reached the limit values at the 13th floor, while according to EN1991-1 it was reached the theoretical limit at the 15th floor level in the x-orientation and 30th floor in the y-orientation. Additionally, this difference shown to be more extensive for Racetrack. For Racetrack while the EN1991-1 reaches 20th floor, ASCE reaches the theoretical limit at 13th floor. Which indicates a %35 deviation for exceeding determined limits. Furthermore, similar differences were observed between EN1991-1 calculations for Compact Square and ASCE 7-22 calculations. While EN1991-1 reaches the limit values at the 35th floor in x orientation, ASCE 7-22 reaches them at the 15th floor. This corresponds to a deviation of 57.14% between the two values.

The primary explanation for the more substantial discrepancies noted in RMS acceleration in contrast to wind analyses can be attributed to the methodological approach wherein wind pressures incorporated into the RMS acceleration computations are applied in an exponential manner within the formulations. This exponential application significantly influences the outcomes, leading to larger variances when compared to the linear analyses typically employed in evaluating wind pressures. In addition to previously mentioned issues, ASCE 7-22 does not recommend different coefficients depending on the L/B ratio on the windward surface, as shown in Table 3.10 (49). These coefficient assumptions also prevent orientation-dependent analysis for ASCE 7-22. On the other hand, the final values recommended by ASCE 7-22 are more in compliance with the critical values of the orientation analysis calculated by EN1991-1.

5.3. Roof Pressures and Roof Selection

This section is formalized to present and discuss the data obtained for research question 4 (Question 4: Can preliminary wind calculations yield a criterion in selection of roof type during design phase? What is the relationship among form, wind pressure and roof type?). Within the context of this thesis, the term “morphology,” as explained in Chapter 1, refers to the overall mass of healthcare facilities. Therefore, the roof of the structure, which holds great importance in terms of wind pressures, is one of the leading research topics in this framework. Examinations were made according to four roof types (flat, mono pitched, duo pitched, hipped) specified by EN1991-1, for three different layouts (Single Corridor, Racetrack, Compact Square).

The calculation of roof loads within EN1991-1 follows a similar method to the calculation of wind loads acting on facades. According to this method, the calculated wind pressure value is multiplied by coefficients provided by the code. When these coefficients are analyzed, in most cases, the most critical loading occurs at the corners (zone F), which is perpendicular to the wind direction (Alrawashdeh and Stathopoulos 2015). However, in duopitched roof, at a slope of 30 degrees, the pressure at Zone G is higher than at Zone F. Furthermore, for pressures at Zone F in duopitched roofs and hipped roofs "wind forces in this region changes rapidly between positive and negative values on the windward face at pitch angle of +5° to +45°" as stated in EN1991-1. Therefore, for this region, in some cases, both negative and positive pressure coefficients provided by EN1991-1.

As seen in the calculations made within EN1991-1 (Figure 4.9a, 4.9b, 4.9c, 63), the type that gives the lowest pressure values for point F among the roof types is the hipped roof. The most important reason for this is that the wind direction is variable when making wind calculations, so calculations are made in both orientations. Accordingly, when the duopitched and monopitched roof types are examined in the F region, it is observed that the roofs exhibit similar behavior to the hipped roof in one orientation. At the same time, they are exposed to more pressure in the other direction.

Another point that needs to be considered for point F is that the forces occurring at this point are suction forces. The wind effect may remove the coating materials used in these areas. The effect of this removal is not only limited to the damage on the roof, but also the damages occurring in these areas cause the roofs to be damaged due to water damage later. For this reason, the connection details in the corner areas of the roofs gain importance (Lee et al. 2013).

Based on the analysis conducted within the framework of this thesis, it was determined that among the various roof configurations evaluated, the monopitched roof configuration exhibited the highest-pressure values across all the slopes analyzed. Consequently, it can be inferred that this roof configuration is the least economically advantageous in comparison to the other roof types considered in this study.

In the fragility analysis, when the F region is examined in terms of material failure, it is seen that roofs with 5% slope exhibit similar material behavior to flat roofs regardless of roof type. A key finding from our analysis is that the pressure coefficients for roofs, as outlined in EN1991-1, display higher values for roofs with a 5% slope in comparison to those with different slopes. This distinction highlights the critical need to factor in slope variations when conducting structural analysis and design of roofing systems to guarantee their stability under diverse environmental loads.

Furthermore, our fragility analysis revealed notable differences in how monopitched and duopitched roofs respond to wind forces coming from two directions. Specifically, for monopitched roofs, the wind impacting perpendicularly to the higher side of the roof results in elevated pressure values in Zone F. Conversely, when the wind impacts the lower side, the pressure values decrease. It's important to note that during the evaluation of these pressure values, the selection of materials was based on the most severe loading conditions encountered. Consequently, the highest-pressure values were incorporated into the fragility analysis. As a result, when constructing the fragility curves for both monopitch and duopitch roofs, the analysis focused on wind load data impacting the structure from a singular orientation. On the other hand, for hipped and flat roofs, the analysis accounted for both orientations due to their similar response patterns to wind forces from any direction. This approach revealed that, for hipped roofs, the same materials require a significantly greater building height to reach failure, highlighting the importance of considering roof type and orientation in structural design and analysis.

5.4. Suitability of Building Motion Limits to Healthcare Facilities

Hospital structures are often characterized as complex, owing to the multifaceted nature of their operational, clinical, and administrative functions. This complexity derives from the necessity to integrate a wide range of services and departments, each with specialized requirements, within a single organizational framework. The intricate interplay between these components ensures the provision of comprehensive healthcare services but also presents significant challenges in terms of coordination, resource allocation, and management. Therefore, classifying these structures can also be challenging, considering different threshold limits. In this manner, the classification of building motion stems from the understanding that hospitals, much like traditional commercial entities, offer services to the public, aligning with the definitional criteria of commercial buildings. According to Griffis' (1993) building motion threshold limits, hospital buildings are categorized within commercial buildings, primarily due to their service-oriented nature. Consequently, the proposed limits for hospital buildings are the same as those for any other commercial building. However, it should also be noted that the current point of view in the literature on healthcare facilities in this manner necessitates further studies to verify the availability of this assumption.

On this topic, it is imperative to recognize that hospital environments cater at least two distinct user groups regarding building motion perception, each group with divergent routines: healthcare professionals, and patients. The daily activities characteristic of these groups, alongside the threshold values that ought to be considered for analytical purposes, demonstrate variability. This variability gains importance in the sense that the perception of motion changes due to the activity performed by the receiver. Kwok (2013) suggests that individuals preoccupied with a primary task show higher tolerance to building motion. This indicates that the perception of building motion may differ depending on the activities performed by patients and healthcare professionals.

According to the motions imposed on these different user groups, they require different limits even though they exist in the same environment. As Tigli (2019) points out in his argument, within the same spatial confines, the perception of motion experienced by occupants varies following the nature of the activities they engage in. This variance in perceptual experience underscores the intricate relationship between human action and spatial cognition, suggesting that physical engagement with space dynamically influences how motion within that space is perceived. On the contrary, literature often presents proposed limit values for specific spaces as a single threshold without distinguishing between different functions that might occur within the same space (Tigli 2019). In buildings with multiple functions and user profiles, such as Healthcare buildings, this dilemma may create uncertainties in the limits that should be taken as a basis. On the other hand, in these uncertain situations, an attitude based on the lowest threshold may be unsustainable and lead to unnecessary costs.

As mentioned in Chapter 2, there are different opinions about the limits of the values and the types of data on which these limits should be based (Kwok 2009; Kwok 2013; Zhu 2014; Demir et al. 2024). The disparities in viewpoints regarding the computation of building motion can be reviewed in 3 aspects: the comparison between Root Mean Square (RMS) and Peak Acceleration (Boggs and Petersen 1997), the divergence between comfort and perception (Kwok 2009), and the involvement of the duration factor (Burton et al. 2007).

RMS acceleration is the number of times and the length of time above the limits of human comfort and the duration of these cycles. In addition, peak acceleration is based on the highest motion encountered; this view grounds its argument on the view that humans tend to forget minor motions, and their reaction depends on the most extensive vibration. In this sense, it is argued that while peak acceleration gives more accurate conclusions on the alarm states of occupants, RMS acceleration more accurately expresses the long-term human comfort criteria (Kwok 2009).

On further notice, some experiments (Denoon et al. 1999; Denoon 2000; Burton et al. 2006; Tamura et al. 2006; Denoon et al. 2011; Michaels et al. 2013) are based on sinusoidal motions but building motions due to wind loads do not have rhythmic characteristics. Human perception does not respond similarly to complex and unpredictable motions and exhibits lower comfort limits in these characteristics (Kwok 2013). Accordingly, the transition evaluations based on the change in the multiplication by $\sqrt{2}$ between peak acceleration and RMS for sinusoidal motion given in various sources (Boggs 1997; Johann et al. 2015) do not give a one-to-one output (Bashor et al. 2005). However, it gives an idea of real situations for wind-induced building motion. Burton et al. (2007) emphasizes the significance of time in their study of how wind events affect people's comfort. Burton and his colleagues found that those subjected to prolonged vibration had a higher propensity to complain and feel uncomfortable compared to those subjected to shorter vibration intervals.

Furthermore, one of the features distinguishing healthcare facilities from other structures regarding building motion limits is the sensitive equipment and precision operations these buildings host. Medical equipment is constantly developing and improving. This constant change, in turn, leads to the use of more vibration-sensitive medical equipment (Wong and Wesolowsky 2018). The increasing sensitivity of medical equipment leads to enhanced attention to the vibration limits this equipment can endure. Moreover, healthcare facilities need to ensure not only that their equipment functions reliably under normal conditions but also that it can operate effectively in extreme weather situations. In this framework, these tools' spatial positioning is becoming increasingly important. In terms of design, the relationships of the spaces where these tools will be located with other spaces and the heights at which they are located should also be examined. Therefore, standardization of space requirements gains importance, considering that the locations of these instruments in healthcare facilities may change over time, that these instruments may be replaced with more sensitive ones, or that the values specified in the specifications of different brands and models may differ.

Furthermore, considering building motion results given in Chapter 4, it can be argued that the design principles adopted in the design of healthcare facilities can be considered as an input that increases the tolerance to reach these limits and accordingly increases both the efficiency of these devices and the comfort of patients and employees. In this regard, the results presented in Chapter 4 (Figures 4.15a, 4.15b, 4.16, 80-81) illustrate that Compact Square, Type 3, can accommodate the highest number of stories without surpassing the limit values, irrespective of the calculation method employed. Accordingly, the decisions taken by the designer allow the building to perform better, even though the same limit values are accepted. In this instance, adopting a morphological design approach that incorporates wind impact considerations into the foundational design principles for buildings situated in areas of higher risk can significantly enhance the comfort levels of occupants within the space. Furthermore, integrating such considerations into the design process from the outset can aid in mitigating subsequent costs that may emerge.

CHAPTER 6

CONCLUSION

This thesis analyzed the effect of morphological aspects, such as the geometry of plan layouts and roof selection, on wind loads in the context of healthcare facilities. Moreover, to widen the understanding of the effect, it further analyses the impact of different wind loads in terms of human discomfort caused by wind-induced building motion. The study focuses on addressing these concerns in the specific area of inpatient units. With the aim of explain the concerns and the findings of the study, the summary of the study was constructed as the research timeline. Therefore, it will provide the reader with the research questions, achieved answers and problems encountered at each stage of the research.

In the first stage of process, the aim was to understand the relation between design decisions, morphology, and wind-loads. First problem encountered was how to calculate and address these wind loads. Therefore, the first act was the investigation of calculation methods. At this stage, two of the various methodologies were selected and analyzed, namely EN1991-1 and ASCE 7-22, and it was found that there were differences between these methodologies. These differences include, EN1991-1 is based on a 10-minute average value when taking the basic wind speed, whereas ASCE 7-22 is based on a 3-minute gust wind speed, the differences in the coefficients taken depending on the environmental factors, the different number and characteristics of the groups to be used in the analysis of environmental factors and the inability to make a one-to-one matching accordingly, the different zone nomenclature and dimensions and the different coefficients assigned to these zones. The question that arises from this is how much of a difference these different approaches to the calculations cause between the results, and which factors affect this difference the most.

Accordingly, in the second stage, different morphologies created by different design approaches in the inpatient floors of hospital buildings. Generic floor plans were designed based on these classes. To analyze these different morphologies for wind, a building matrix containing 1080 calculation states depending on six variables (geometry, directionality, height, roof type, roof slope, and exposure category) for a single speed was created, and a computer software was developed. Based on the results of the calculations, it was observed that the wind load calculations varied at different rates depending on various parameters in both codes. For peak velocity pressure, the results obtained were higher in EN1991-1 in relation to velocity, indicating that the results for both codes diverge from each other as the wind speed increases. In addition, when comparing the relationship between peak velocity pressure and height, it is observed that this relationship significantly differs according to the exposure categories. Based on the data, the highest differences are observed in the environmental factors categorized as Exposure D by ASCE 7-22, and Terrain Category 0 according to EN1991-1, the highest wind pressure values are noted in both codes. When analyzing each façade individually, it is found that ASCE 7-22 yields higher results in buildings with less height, whereas the results obtained by using EN1991-1 are higher in taller buildings. As for the roof, the calculations show that different roof types exhibit different performances. In parallel with the results given in the literature, the hipped roof showed the best performance. In addition, it was observed that all roof types exhibited fragility similar to the flat roof in the corner areas in the analyses made on the types with a 5% slope.

Therefore, an additional question emerged as an outcome of the results focused on a deeper exploration of the interplay between the observed outcomes and architectural principles. This inquiry led to a third phase in the research, which aimed to accurately quantify the motions of buildings subjected to wind loads, as derived from the earlier findings. This phase involved calculations of these building motions, which were then compared against established limit values as outlined in the relevant literature. In this context, the best performing type was Compact Square with an aspect ratio of 1. On the other hand, the building configuration that reaches the limit values at the lowest height is the Single Corridor type where the wind acts from the long side. These differences are found to escalate with increasing wind force and building height. Furthermore, research has established that variations exist among inpatient floors of differing morphologies, even when evaluated under a uniform code. Therefore, the examination of building dynamics alongside human comfort levels, as dictated by the one code, indicates that these disparities lead to the exceedance of comfort limits at different levels of the building.

It is also noted that healthcare environments host two different user groups and the wind-induced motion comfort limits for these two groups are identical and equal to those of any other commercial building. It is essential to reevaluate to accommodate the diverse requirements of various user groups within such healthcare settings. Furthermore, depending on the functions of hospital buildings, the medical equipment they contain have vibration limits below human comfort limits. Therefore, even if the required human comfort limits are provided for hospital buildings, the locations and special needs of these equipment should be considered in areas with specific hospital functions.

There is a growing body of literature that investigates the results of spatial and morphological design decisions of hospital buildings (Heo et al. 2009; Lu et al. 2009; Sailer et al. 2009; Cai and Zimring 2012; Koch and Steen 2012; Kasalı et al. 2013 Pachilova and Sailer, 2015). Nevertheless, there is a scarcity of research investigating the implications of the interplay between morphological characteristics and structural determinants on the internal dynamics of healthcare institutions and the well-being of their patients. As Latimer and his colleagues (2008, 80-82) argue the influential factors, advanced care methods, rapid technological progress, and consumer culture, signifies a significant shift towards more intricate healthcare infrastructures, are triggering the growth of inpatient floors of healthcare facilities. While the reasons and necessity of this growth are discussed, its effects on the functioning of health structures are also a subject that requires investigation.

In the particular case of Turkey, it is seen that not only room-based growth but also a growth in total hospital masses due to the reforms in the health system is observed. A health model has been proposed that involves the construction of health facilities operated through a "public-private partnership" model called "city hospitals" (Konuralp and Bicer 2021). City hospitals are positioned to address advanced care needs that hospitals in their respective regions cannot meet. Due to these qualities, the technology and equipment they house are relatively more advanced, and they have larger masses than hospitals located within urban areas. In addition, another issue that may be important in the wind manner is that these buildings are usually located on the outer peripheries of cities due to their large mass. In this case, the types of exposure they are covered by differ from those in urban areas due to the decreased number of buildings surrounding them. Accordingly, these structures should be subjected to more scrutiny due to their large mass, location, the sensitivity of the operations performed, and the requirements of the medical instruments and imaging systems they contain.

Therefore, this thesis investigates the correlation between structural morphology and wind-induced loads, further exploring the consequent repercussions for the hospital's occupants. The calculations indicate discrepancies in the codes due to environmental assumptions. The results highlight notable differences in wind load calculations across codes concerning wind speed, building height, and environmental assumptions. Empirical evidence has consistently demonstrated that differences among code responses exhibit notable variations proportionally with wind velocity, with the most pronounced differences observed in structures situated in direct exposure to wind, particularly those located in coastal regions.

Given the data presented, it can be concluded that, the differential outcomes underscore the significance of morphological decisions and highlights the need for a nuanced understanding of how different standards can influence the assessment of building safety and human comfort under wind load conditions. The study underlines the importance of evaluating building safety and human comfort under wind loads, emphasizing the need for a comprehensive understanding of different standards. This investigation offers valuable insights for architects in designing inpatient units to improve both structural integrity and occupant comfort.

6.1. Limitations and Further Studies

The calculations conducted for this thesis were premised on hypothetical hospital structures to ensure comparability. As a result, the research can be described as highly controlled, with all variables except the considered parameters being held constant. Furthermore, the study did not factor in national annexes tailored to specific countries, meaning variations stemming from environmental data recommended by certain codes were overlooked. To address this, it is advisable to replicate the calculations using case studies to test the differences highlighted by the codes against actual data. Moreover, for a comprehensive analysis of different RMS data and comfort thresholds, it would be prudent to collect vibration data from case studies. This data, coupled with survey responses from building occupants, can help validate the limit values and ascertain which code's recommendations closely align with real-world findings.

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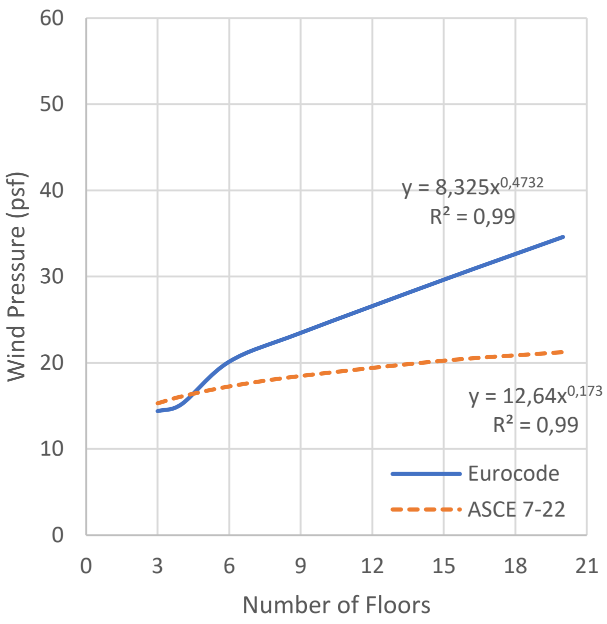
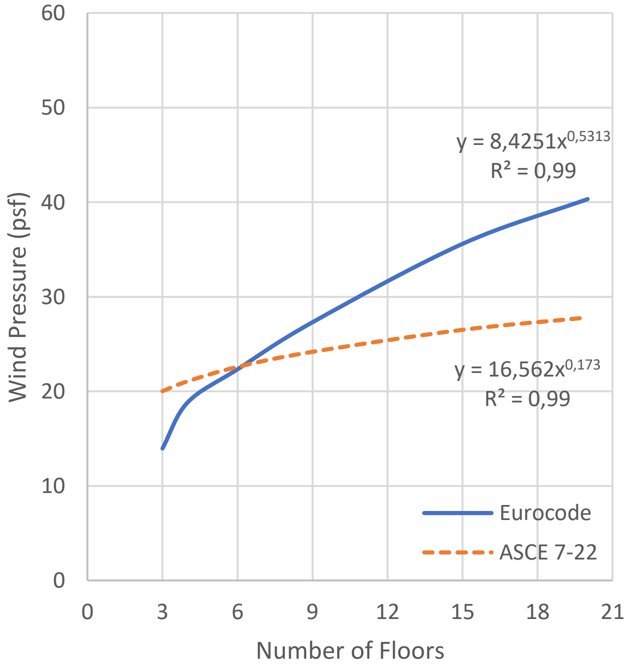
APPENDICES

APPENDIX A. CALCULATION RESULTS

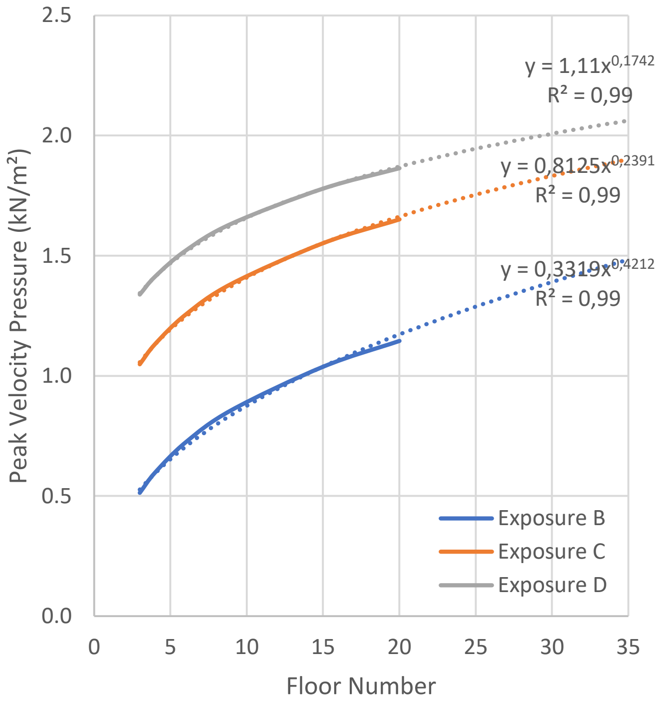
A.1. Wind Pressure- Number of Floors for Type 2 on Leeward Wall



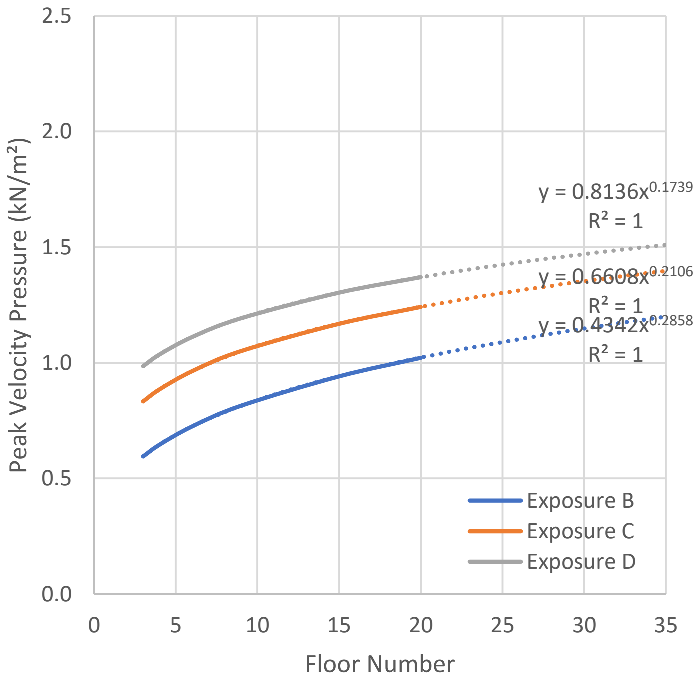
A.2. Wind Pressure- Number of Floors for Type 3 on Leeward Wall



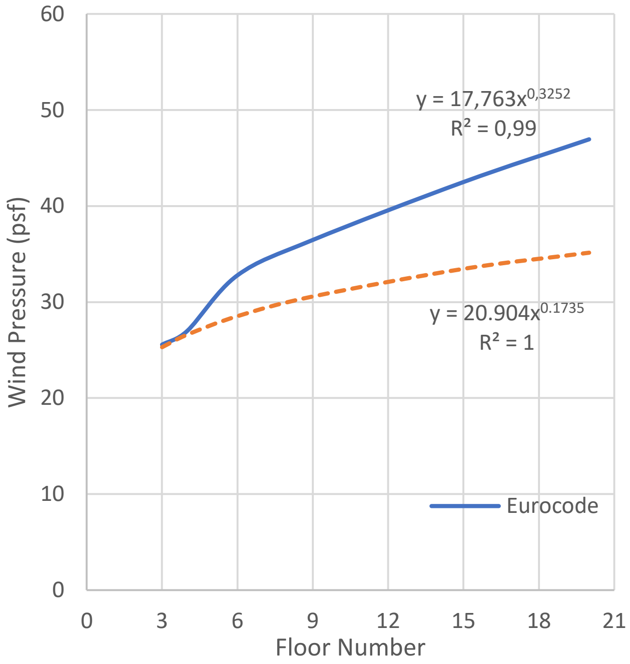
A.3. Peak Velocity Pressure-Number of Floors for EN1991-4 (V= 27 m/s)



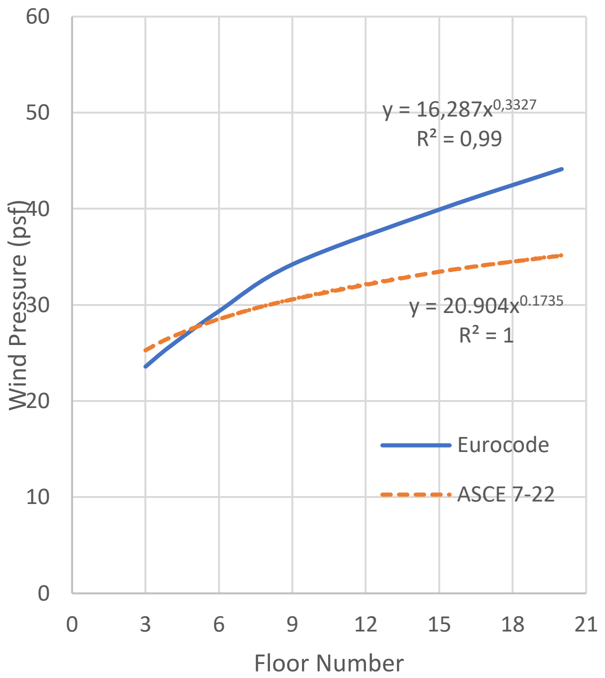
A.4. Peak Velocity Pressure-Number of Floors for ASCE 7-22 (V= 27 m/s)



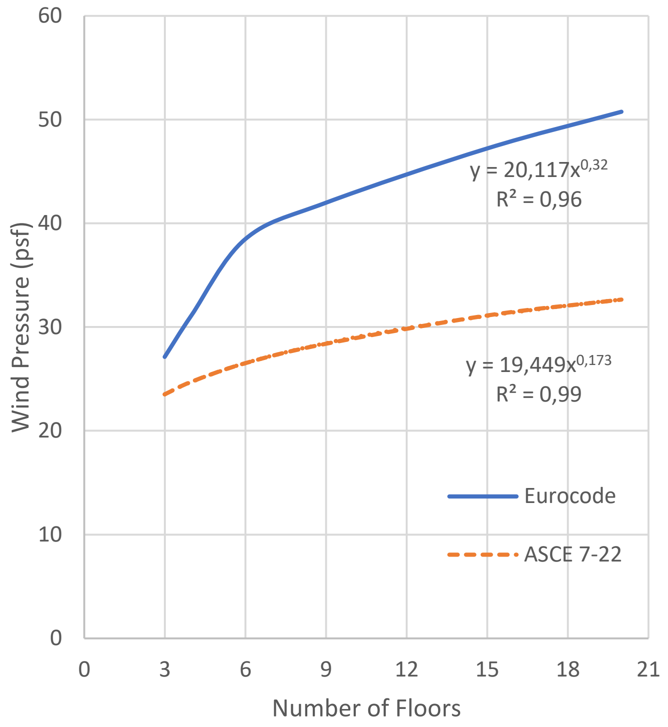
A.5. Wind Pressure- Number of Floors for Racetrack on Winward Wall (Directionality x)



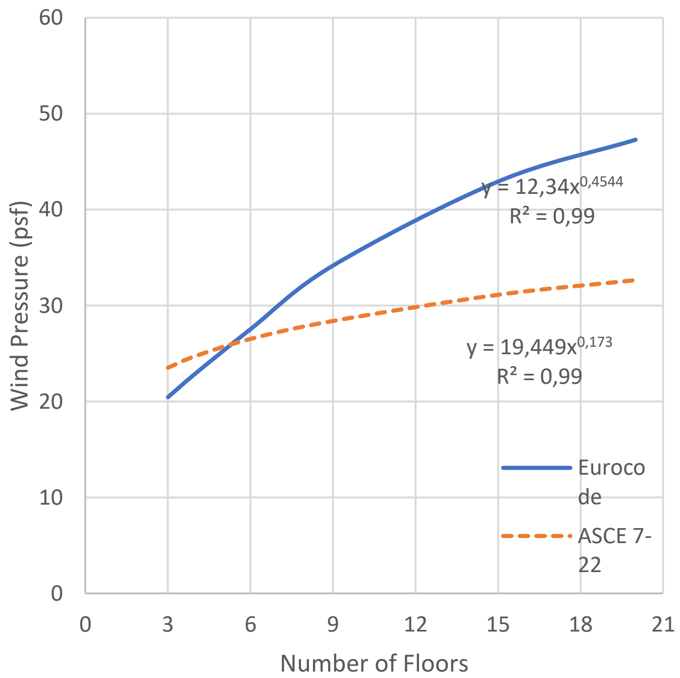
A.6. Wind Pressure- Number of Floors for Racetrack on Winward Wall (Directionality y)



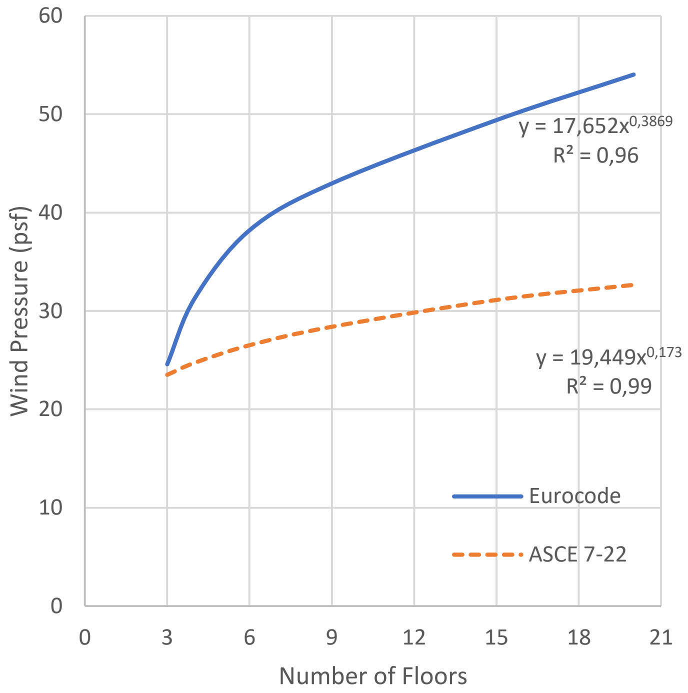
A.7. Side Wall Wind Pressures for Type 2 (Racetrack-Directionality x)



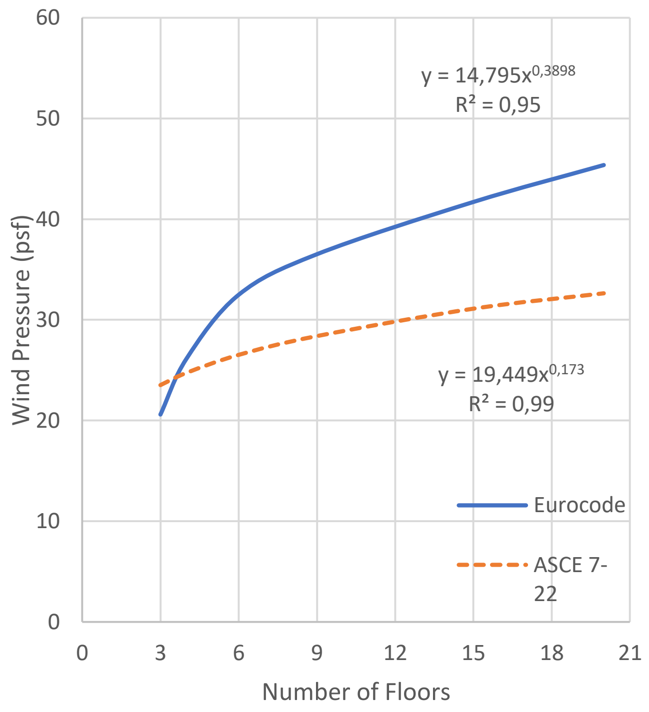
A.8. Side Wall Wind Pressures for Type 2 (Racetrack-Directionality y)



A.9. Side Wall Wind Pressures for Type 3 (Compact Square-Directionality x)



A.10. Side Wall Wind Pressures for Type 3 (Compact Square-Directionality y)



APPENDIX B. EN1991-1-4 and ASCE 7-22 REFERENCE TABLES

B.1. Figure 4.2 from EN1991-1-4

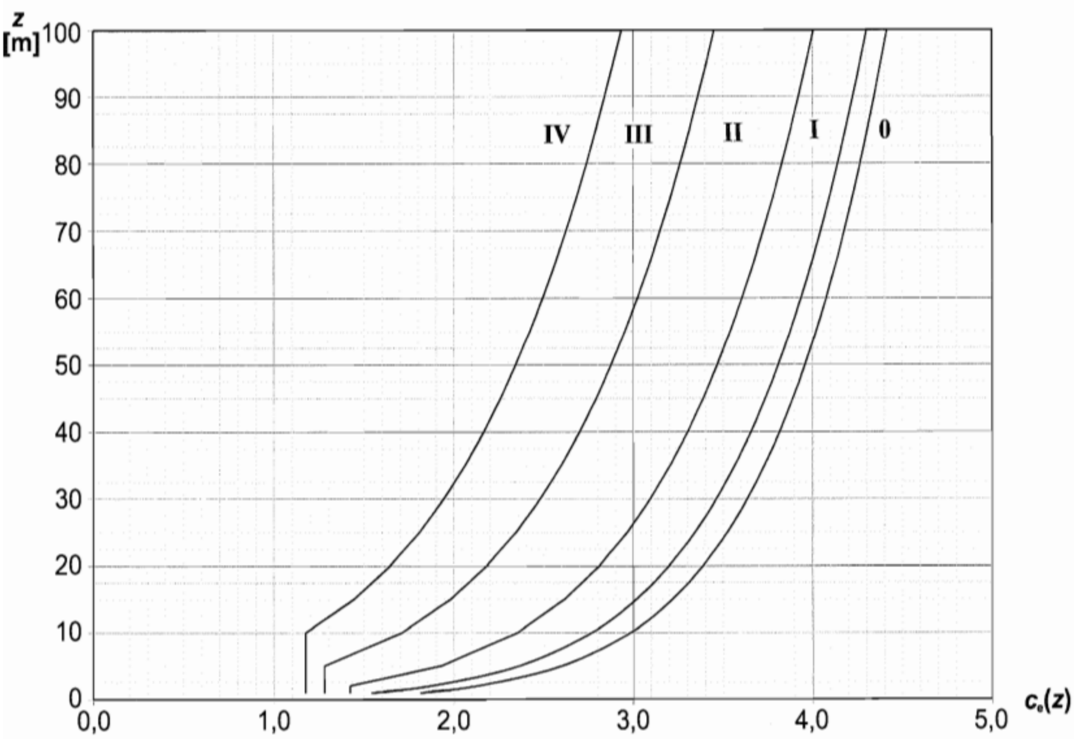
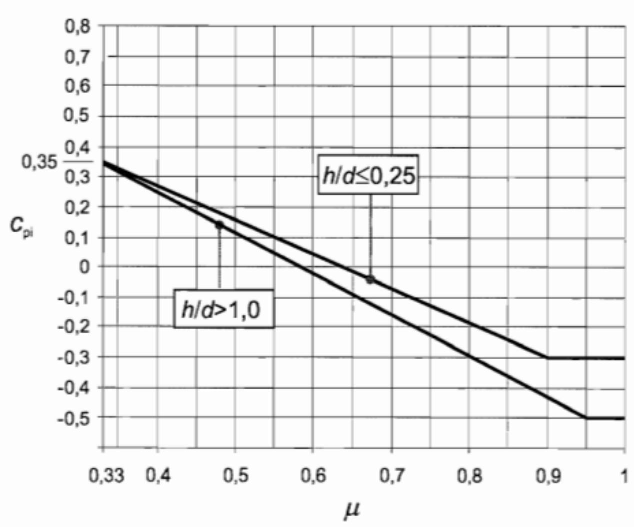


Figure 4.2 — Illustrations of the exposure factor $c_e(z)$ for c_O=1,0, k_I=1,0

B.2. Figure 7.13 from EN1991-1-4



NOTE For values between h/d = 0,25 and h/d = 1,0 linear interpolation may be used.

B.3. Table 26.9-1 Ground Elevation Factor, K_e from ASCE 7-22

Table 26.9-1 Ground Elevation Factor, K_e

Ground Elevation above Sea Level		Ground Elevation Factor
ft	m	K_e
<0	<0	See note 2
0	0	1.00
1,000	305	0.96
2,000	610	0.93
3,000	914	0.90
4,000	1,219	0.86
5,000	1,524	0.83
6,000	1,829	0.80
>6,000	>1,829	See note 2

Notes

1. The conservative approximation $K_e = 1.00$ is permitted in all cases.
2. The factor K_e shall be determined from the above table using interpolation or from the following formula for all elevations:
   $K_e = e^{-0.0000362 z_g}$ (z_g = ground elevation above sea level in ft).
   $K_e = e^{-0.000119 z_g}$ (z_g = ground elevation above sea level in m).
3. K_e is permitted to be take as 1.00 in all cases.

B.4. Table 26.11-1 Terrain Exposure Constants from ASCE 7-22

Table 26.11-1 Terrain Exposure Constants

Customary Units										
Exposure	α	z_g (ft)	$\hat{a}$	$\hat{b}$	$\bar{\alpha}$	$\bar{b}$	c	ℓ (ft)	$\bar{\epsilon}$	z_{min} (ft)[a]
B	7.0	1,200	1/70	0.84	1/4.0	0.45	0.30	320	1/3.0	30
C	9.5	900	1/9.5	1.00	1/6.5	0.65	0.20	500	1/5.0	15
D	11.5	700	1/11.5	1.07	1/9.0	0.80	0.15	650	1/8.0	7
S.I. Units										
Exposure	α	z_g (m)	$\hat{a}$	$\hat{b}$	$\bar{\alpha}$	$\bar{b}$	c	ℓ (m)	$\bar{\epsilon}$	z_{min} (m)[a]
B	7.0	365.76	1/7	0.84	1/4.0	0.45	0.30	97.54	1/3.0	9.14
C	9.5	274.32	1/9.5	1.00	1/6.5	0.65	0.20	152.40	1/5.0	4.57
D	11.5	213.36	1/11.5	1.07	1/9.0	0.80	0.15	198.12	1/8.0	2.13

[a] z_{min} = minimum height used to ensure that the equivalent height $\bar{z}$ is the greater of $0.6h$ or z_{min}. For buildings or other structures with $h \le z_{min}$, $\bar{z}$ shall be taken as z_{min}.

APPENDIX C. EXAMPLE CALCULATION FOR 1x53a3

This appendix is designed to present the detailed progress of the calculations. For this purpose, the calculation process of the hospital structure 1x53a3, selected as an example, is given below. The features of the structure described are as follows: a single corridor plan type exposed to wind from the short side, 15 stories, with a duo-pitched roof having a 5 percent slope, in exposure category D.

C.1. EN1991-1-4 Wind Load Calculations

Where the 10-minute average speed is 27 m/s, directionality factor is 1 and seasonal factor is 1:

$$V_b = C_{dir} \,.\, C_{season}.\, V_{b,0} = 1 \,.\, 1 \,.\, 27 = 27\ m/s$$

V_b: Basic wind speed (m/s)
C_{dir} : Directionality factor
C_{season}: Seasonal factor
$V_{b,0}$: 10-minute average wind speed (m/s)

With the assumption that Exposure B is equivalent to Terrain Category 0, the Roughness length correction factor (k_r) is calculated as:

$$k_r = 0{,}19 \,.\left(\frac{z_0}{z_{0,II}}\right)^{0{,}07} = 0{,}19 \,.\left(\frac{0{,}003}{0{,}05}\right)^{0{,}07} = 0{,}1560$$

k_r: Roughness length correction factor
z_0: Roughness length (m)
$z_{0,II}$: Roughness length for terrain category II (m)

$$c_r(z) = k_r. \ln\left(\frac{z}{z_0}\right) = 0{,}1560 \ . \ \ln\left(\frac{45}{0{,}003}\right) = 1{,}5004$$

$c_r(z)$: Velocity pressure exposure coefficient at height z

$$V_m(z) = c_r(z).\, c_0(z).\, V_b = 1{,}5004 \,.\, 1 \,.\, 27 = 40{,}511$$

$V_m(z)$: Mean wind speed at height z (m/s)
$c_0(z)$: Gust response factor at height z

$I_v(z) = \frac{k_l}{c_0(z).\ln(z/z_0)} = \frac{1}{1.\ln(45/0{,}003)} = 0{,}104$

$I_v(z)$: Turbulence intensity at height z

k_l: Turbulence length scale factor

$$q_p(z) = [1 + 7.I_v(z)].\frac{1}{2}.\rho.v_m^2(z) = [1 + 7.0{,}104].\frac{1}{2}.1{,}25.27^2 = 1772{,}405$$

$q_p(z)$: Peak wind pressure at height z (Pa)

ρ: Air density (kg/m³)

For the continuation of the calculation, it is necessary to know whether the building has a dominant face or not. For the given example, the building has no dominant face. In cases with no dominant face, the m ratio is calculated using the formula below.

$$\mu = \frac{\sum \text{area of opennings where } c_{pe} \text{ is negative or} -0{,}0}{\sum \text{area of all opennings}} = \frac{78{,}75}{1775{,}5} = 0{,}444$$

Internal pressure value is found from the graph given in Eurocode Figure 7.13 (Appendix B.2, 114).

c_{pi} = -0,560

$w_i = q_p(z_i).c_{pi}$

w_i: internal wind pressure

c_{pi}: internal pressure coefficient

q_p: peak velocity pressure

$w_e = q_p(z_e).c_{pe}$

w_e: external wind pressure

c_{pe}: external pressure coefficient

q_p: peak velocity pressure

In the last step, external pressures are calculated. For this, the coefficients given for each region are multiplied by the corresponding q_p's. Total pressure is calculated based on internal and external pressures. In table C.1.1. below, the results of each region for the relevant structure are given.

Table C.1.1. EN1991-1-4 Calculation Results for 1x53a3

Zones		Surface Coefficients (c_{pe})	Surface Pressures (Pa)
Side Wall	A	-1.2	-3120.110
	B	-0.8	-2411.148
	C	-0.5	-1879.427
Windward Wall	D	0.736	2298.484
Leeward Wall	E	-0.372	-1654.098
Roof	F	-1.6	-3829.072
	G	-1.3	-3297.351
	H	-0.7	-2233.908
	I	-0.6	-2056.667

C.2. ASCE 7-22 Wind Load Calculations

To perform the calculations based on ASCE 7-22, the 10-minute average speed data must first be converted to 3-second gust speed.

$$V_{ref}^{3sec} = \frac{V_{ref}^{10\,min}}{0{,}67} = \frac{27}{0{,}67} = 40\ m/s$$

In the next step, the peak velocity pressure should be calculated. In this study, K_{zt} and K_e are taken as 1 and K_d is taken as 0.85 as given in Chapter 3.3. For the calculation of K_z, the values in Table 3.8 (47) were used.

$$K_z = 2{,}01\left(\frac{z}{z_g}\right)^{\frac{2}{\alpha}} = 2{,}01\left(\frac{45}{213{,}36}\right)^{\frac{2}{11{,}5}} = 1{,}53$$

$$q_z = 0{,}613 K_z K_{zt} K_d K_e V^2 = 0{,}613.\, 1{,}53\, .\, 1.\, 0{,}85\, .\, 1\, .\, 40^2 = 21297.494$$

K_z:velocity pressure exposure coefficient
K_{zt}: topographic factor
K_d: wind directionality factor
K_e: ground elevation factor
V: basic wind speed
q_z: velocity pressure at height z.

After the computation of velocity pressure, the process of calculating design wind pressure is initiated. The details of the assumptions made for this calculation are explained in Chapter 3.3.3.

$p = qGC_p - q_i(GC_{pi})$

p: Design wind pressures

q: q_z at height z above the ground.

G: gust-effect factor

C_p: external pressure coefficient

GC_{pi}: internal pressure coefficient

The results of design wind pressure calculations and C_p values are given in table C.2.1.

Table C.2.1. ASCE 7-22 Calculation Results for 1x53a3

Zones	Surface Coefficients (c_p)	Surface Pressures (lb/ft2)
Side Wall	-0,7	-27.76
Windward Wall	0,8	29.85
Leeward Wall	-0,2	-17.46

C.3. Motion Perception Calculations

Within the sample calculation, an illustration of the RMS acceleration value calculation is given only for Eurocode Zone D.

$$T = 0{,}904H\left(\frac{\rho D_r}{pR}\right)^{0.5} = 0{,}904\,.\,147{,}63\left(\frac{15{,}3\,.\,0{,}0025}{65{,}16\,.\;1{,}0588}\right)^{0.5} = 3{,}142$$

T: building period in seconds

ρ: density (PCF)

H : building height (feet)

D_r: design drift ratio (Δ/H)

p: equivalent uniform pressure (PSF)

R: aspect ratio H/B

$$K = (2\pi N)^2 \times M = (2\pi.0{,}318)^2 \times 1{,}991 = 7{,}9608$$

K: generalized stiffness (newton/meters)

N: frequency (hertz)

M: generalized mass of the building (kilogram)

$C_D(Z) = 0.0116 \times B^{0.26} \times Z = 0{,}0116 \times 42{,}497^{0.26} \times 45 = 1{,}383$

$C_L(Z) = 0.0263 \times B^{-0.54} \times Z = 0.0263 \times 42{,}497^{-0.54} \times 45 = 0{,}156$

$C_D(Z), C_L(Z), C_\theta(Z)$: proportionality constants

B: plan dimension (meters)

Z: building height (meters)

Since the speed value to be taken within the calculation is equal to the hourly average speed, the speed values are exchanged.

$$U_H = V_{ref}^{1h} = \frac{V_{ref}^{10\,min}}{1{,}05} = 25{,}71$$

U_H: mean hourly wind speed (m/s)

Afterwards, it is checked whether the following is greater than 0.25 and the appropriate formula is selected based on this value.

$$\frac{N_\theta B}{U_H} = \frac{0{,}374\ \times\ 42{,}497}{25{,}71} = 0{,}526$$

$$C_\theta(Z) = 0.00510 \times B^{1.24} \times Z \quad = 0.00510 \times 42{,}497^{1.24} \times 45\ = 23{,}985$$

$$A_D(Z) = C_D(Z)\frac{U_H^{2,74}}{K_D^{0,37} \times \zeta^{0,5} \times M_D^{0,63}} = 1{,}383 \times \frac{25{,}71^{2,74}}{7{,}9608^{0,37} \times 0{,}01^{0,5} \times 1{,}991^{0,63}}$$
$$= 0{,}003$$

$$A_L(Z) = C_L(Z)\frac{U_H^{3.54}}{K_D^{0.77} \times \zeta^{0.5} \times M_L^{0.23}} = C_L(Z)\frac{25{,}71^{3,54}}{7{,}9608^{0,77} \times 0{,}01^{0.5} \times 1{,}991^{0,23}}$$
$$= 0{,}002$$

$$A_\theta(Z) = C_\theta(Z)\frac{U_H^{2.76}}{K_\theta^{0.38} \times \zeta^{0.5} \times M_\theta^{0.62}} = C_\theta(Z)\frac{25{,}71^{2,76}}{1{,}1018^{0,38} \times 0{,}01^{0.5} \times 1{,}991^{0,62}}$$
$$= 0{,}049$$

$$A_R = (A_D^2 + A_L^2 + \left(B/\sqrt{2} \times A_\theta\right)^2)^{0.5}$$
$$= (0{,}003^2 + 0{,}002^2 + \left(42{,}497/\sqrt{2} \times 0{,}049\right)^2)^{0.5} =\ 4.835$$

$A_D(Z),\ A_L(Z),\ A_\theta(Z)$: along-wind, across-wind, and torsional RMS acceleration

A_R: resultant RMS acceleration

ζ: damping ratio