SUSTAINABILITY OF HIGH-RISE BUILDINGS: ENERGY CONSUMPTION BY SERVICE CORE CONFIGURATION

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE IN BUILDING SCIENCE
IN
ARCHITECTURE

SEPTEMBER 2012

Approval of the thesis:

SUSTAINABILITY OF HIGH-RISE BUILDINGS:
SERVICE CORE CONFIGURATION

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ABSTRACT

SUSTAINABILITY OF HIGH-RISE BUILDINGS: ENERGY CONSUMPTION BY SERVICE CORE CONFIGURATION

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September 2012, 120 pages

The concept of 'sustainability' came into question during the last few decades world-wide. As one of the main source of carbon emission, construction industry is also affected by this movement. High-rise buildings which became proliferative components of construction industry dominate today's urban centers. Although they are defended as being inherently energy efficient by some people, specially designed sustainable high-rise building examples emerged after the sustainability movement all over the world.

This dissertation examines the role of the service core configuration on the sustainability of high-rise buildings. In this context, the effect of different core types and locations on the energy consumption of high-buildings is evaluated. For this respect, sixteen alternative configuration models with central, end and split core types are determined as the representative of possible design choices. The alternatives share the same height, net and gross floor area, floor efficiency, materials, internal gains, etc. They just vary in type and location of the service core and orientation of the building mass.

Energy consumptions of the sixteen models are tested with *eQUEST*, a thermal simulation program, by using the climatic data of Istanbul. The simulation is conducted according to two air conditioning scenarios for office and core zones. For both of the scenarios, split core alternatives are found as the most energy efficient configurations regardless of the core location and building orientation. Moreover, it is observed that while the end core alternatives giving average values, central core configurations have the highest energy consumption results, as predicted.

Keywords: Service core, service core configuration, high-rise buildings, sustainability, energy consumption optimization , thermal simulation, *eQUEST*.

ÖZ

YÜKSEK BİNALARDA SÜRDÜRÜLEBİLİRLİK: SERVİS ÇEKİRDEĞİ YAPILANMASI YOLUYLA ENERJİ TÜKETİMİ

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'Sürdürülebilirlik' konseptinin son 20-30 senede dünya çapında önem kazanması, karbon salınımının başlıca kaynaklarından olan inşaat sektöründe değişimlere yol açmıştır. Günümüzün kentsel alanlarında baskın olan yüksek binalar da inşaat sektörünün hızla artan öğeleri olarak bu değişimden payını almıştır. Buna rağmen yüksek binaların sürdürülebilirliği tartışmalıdır. Bazı çevreler tarafından doğası gereği enerji etkin olarak değerlendirilmesine rağmen, özel olarak tasarlanan sürdürülebilir yüksek bina örnekleri dünyanın her yerinde görülmeye başlanmıştır.

Bu tez çalışmasının amacı, servis çekirdeği yapılanmasının yüksek binaların sürdürülebilirliğine olan etkisini incelemektir. Çalışma kapsamında farklı servis çekirdeği çeşit ve yerleşimlerinin binanın enerji tüketimine olan etkisi değerlendirilmiştir. Bu amaçla, olası tasarım seçeneklerini temsil eden merkezi, uç ve bölük çekirdek tipolojilerine sahip on altı adet alternatif model oluşturulmuştur. Bu modeller oluşturulurken bina yükseklikleri, net ve brüt alanlar, kat verimliliği oranı, kullanılan malzemeler, insan sayısı, ekipman gibi

değişkenler sabit tutulurken, sadece servis çekirdeklerinin çeşidi, yerleşimi ve bina yönelimleri değiştirilmiştir.

Bahsedilen on altı model, *eQUEST* adında bir termal simulasyon programıyla test edilmiştir. Programda İstanbul'un hava verileri kullanılmış ve simülasyon, ofis ve çekirdek alanları için uygulanan iki farklı iklimlendirme stratejisine göre gerçekleştirilmiştir. İki senaryo için de, 'ayrık çekirdek' tipolojisindeki modeller servis çekirdeğinin yerleşimi ve bina yönlenmesinden bağımsız olarak enerji tüketimi açısından en düşük değerleri almıştır. Bunun yanı sıra, 'uç çekirdek' tipolojisindeki modeller ortalama değerlere, 'merkezi çekirdek' modelleri ise tahmin edildiği gibi en çok enerji tüketmeleriyle ilintili olarak en yüksek değerlere sahip olmuştur.

Anahtar kelimeler: Servis çekirdeği, servis çekirdeği yapılanması, yüksek binalar, sürdürülebilirlik, enerji tüketim optimizasyonu, termal simulasyon, *eQUEST*.

To my family

ACKNOWLEDGEMENTS

I owe my deepest gratitude to my supervisor Assoc. Prof. Dr. M.Halis Günel for his guidance, insight and encouragement throughout the study. It has been a great pleasure and honor to work with him.

I would like to thank to Tübitak-Bideb for all their support which made possible to focus my attention on the thesis.

I would like to express my special thanks and love to my family for their continuous encouragement, patience and support without which this project would not have been possible. Lastly, my little nephew, Peri, deserves a medal for her wonderful smile which has encouraged me to go on.

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ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BEAM	Building Environmental assessment methods
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Building Environment Efficiency
CIBSE	Chartered Institution of Building Services Engineers
CO_2	Carbon Dioxide
CTBUH	Council on Tall Buildings and Urban Habitat
eQUEST	QUick Energy Simulation Tool
GFA	Gross Floor Area
HABITAT	United Nations Human Settlements Programme
HVAC	Heating, Ventilating and Air Conditioning
IES-VE	Integrated Environmental Solutions – Virtual Environment
LEED	Leadership in Energy & Environmental Design
M&E	Mechanical and Electrical
m	meter
NFA	Net Floor area
SBS	Sick Building Syndrome
SOM	Skidmore Owings & Merril
WBCSD	World Business Council for Sustainable Development
VAV	Variable Air Volume

CHAPTER 1

INTRODUCTION

In this chapter, the argument with background information, objectives of the thesis and the general procedure are proposed, respectively. Moreover, the disposition of the report is given at the end of the chapter.

1.1 ARGUMENT

High-rise buildings are inevitable components of contemporary developed cities. Upsurge in urban population, high land costs which lead maximization of land use, ease of accessibility, business requirements, and technological achievements are few of the reasons of high-rise buildings' existence (Yeang & Powell, 2007). Today, the effort to create a skyline concept, and concern for prestige are additional facts of constructing high-rise buildings (Beedle, Ali & Armstrong, 2007a). Ali & Armstrong (2008) state that, while 30 per cent of the total population has dwelled in cities in 1950, this value will reach to 60 per cent by 2030 which is equivalent to 5 billion people. Thus, high-rise buildings will become a necessity rather than a rational choice in the near future.

Another phenomenon that will become a necessity rather than a choice in the near future is sustainability. Gill (2008) notifies that although most of the people think in the other way, it is buildings that have the largest share in the global environmental impact rather than automobiles. He adds that, 80 per cent of the carbon emission in rural areas results from buildings. When high-rise buildings are considered, there are different ideas questioning sustainability. There are those who believe that high-rise buildings are inherently sustainable while others consider them as totally anti-environmental typologies.

High-rise buildings occupy smaller area in the ground level than low-rise buildings corresponding to the same volume, which enables open space for parks, playground and other outdoor activities (Beedle *et al.*, 2007a). Moreover, due to gathering lots of people in a smaller land, high-rise buildings prevent urban sprawl, and help to lower the energy which is consumed for transportation (Beedle *et al.*, 2007b). These are the reasons to defend high-rise buildings as sustainable. However, Yeang & Powell (2007) believe that high-rise buildings are the most unecological type. They claim that when compared to other building typologies, high-rise buildings consume at least three times more energy and material to construct, to run and to demolish. Beedle *et al*. (2007a) also take attention to the huge amounts of energy consumed for the operation of the high-rise buildings, and add the negative social effects of them within the surrounding fabric. In a distinctive manner, Gonçalves & Umakoshi (2010) admit the higher energy demand of the high-rise buildings; however, they associate these problems with the design approach, not the typology.

Designing a sustainable high-rise building involves a multi-disciplinary approach, because it requires special treatment in so many elements such as orientation, form, façade, structure, furnishing, electrical and mechanical controls, etc. (Malin, 2006). To reach a high level of sustainability, architects, engineers, planners, behavioral and social scientists should work in collaboration (Ali & Armstrong, 2008). Thus, to obtain an environmentally sensitive high-rise building, every component should be designed with a special effort, and service core is one of these components having great importance (Trabucco, 2008).

Trabucco (2008) indicates that the importance of service core is ignored due to its hidden location and technical temperament; however, it is crucial for a successful sustainable high-rise building. In fact, Ali & Armstrong (2008: 5) state that “the more time spent on the core design, the more efficient and sustainable the building can be." A sustainable service core design can be branched into several issues. First of all, the energy used by service core itself can be optimized. In this case, every component forming service core has to be designed specially to lower the energy consumption (Trabucco, 2008). Second issue is designing service core in a way to decrease operational energy of the whole building (Trabucco, 2008). Third and the last issue is optimizing the embodied energy consumption of building by service core design (Trabucco, 2008).

While the first issue differs due its technical nature, the latter two issues are related to each other. Designing the components forming service core such as elevators, toilets, HVAC (heating, ventilating and air conditioning), M&E (mechanical and electrical) systems, etc. requires technical knowledge, and is in the field of engineers. Additionally, there are lots of studies and innovations even just about decreasing energy usage of elevator systems in high-rise buildings (Yeang, 1996). On the other hand, optimizing running and embodied energy usage of high-rise buildings by service core design is in the scope of architects, and needs in-depth study.

Embodied and operational energies are very critical issues for high-rise buildings. Because the materials used in these buildings are more energy-expensive per unit area than low-rise buildings (Troy, 2001). Additionally, the 2007 report of World Business Council for Sustainable Development (WBCSD) states that approximately 85 percent of the energy consumed in a building is spent for operation during a 50-year lifespan; while manufacturing, construction, transportation and maintenance share only 15 per cent.

Optimizing operational energy consumption of high-rise buildings by service core design involves special treatment in configuration, material choice, façade, etc. In these topics, there is lack of knowledge in literature about service core configuration. Moreover, the existent studies are not sufficient to reach a complete idea about the issue. The effectiveness of a strategy on service core design largely depends on the geographical location and climatic conditions of the building's locality. Thus, the design strategies would change with the change in location. The conducted studies on the service core configuration generally examine harsh climates such as tropical or cold. However, there is insufficient information to present the situation for places in between those extreme climatic conditions. This study focuses on the effect of service core configuration on sustainability of high-rise buildings considering the energy consumption. The climatic data of Istanbul is processed in the study to serve as a model for cities having similar climatic conditions which require both heating and cooling during a year.

1.2 OBJECTIVES

The main objective of the thesis is to present a design guide for designers involved with the execution of high-rise buildings by establishing useful data on alternative service core configurations and their effects that could be used as a passive design criterion. The other objectives of the thesis are:

- to compare the heating and cooling energy consumptions of alternative service core configurations,

- to verify the Sekkei's study (Yeang, 1999) on the service core configurations and enlighten the contradictious parts of the study,

- to evaluate the accumulated knowledge database on service core configurations and their impact on energy consumption.

1.3 PROCEDURE

The first stage of the study is composed of a literature survey. It is based on articles, books, journals and other publications related with the argument. The survey contains background information about the issue, relevant standards and similar studies conducted on this subject. Thereafter, the study is carried out on a series of hypothetical high-rise buildings. The designs of these buildings are determined by considering the related regulations, standards and some parameters used in the Sekkei's study (Yeang, 1999). The buildings share the same height, floor area, floor efficiency, construction materials, occupation, and operation schedules. They just vary in type and location of the service core and orientation of the building mass. In total, there are sixteen different alternatives as representatives of general design configurations.

In the third phase, these alternatives are analyzed in a computer-aided thermal simulation program. The input parameters are set with the relevant values of regulations, standards and default values of the program. The simulations are realized for two different air conditioning scenarios for service core areas of external core configurations. At the last phase, the simulation results of sixteen different alternatives and two different scenarios are compared among each other in terms of different parameters related to energy consumption.

1.4 DISPOSITION

The report is composed of five chapters. The first chapter which is titled as 'Introduction' covers the argument with background information, objectives of the thesis and the general procedure. It is concluded with a disposition of the study given in the following chapters.

The second chapter presents the literature survey on the subject domain. It consists of a brief information on sustainability in architecture, relationship between high-rise buildings and sustainability, evolution of sustainable high-rise buildings, service core concept, and bio-climatic approach to service core design. The chapter is concluded with an evaluation of the literature survey to summarize accumulated knowledge.

In the third chapter, the survey material and methodology are described. The chosen simulation program is examined, and the design decisions of the hypothetical buildings are discussed.

The forth chapter covers the simulation on the hypothetical high-rise buildings which is carried out for sixteen different alternatives, and the presentation of the results. In the last chapter, the concluding remarks of the survey are presented, and the issues for further research are discussed.

CHAPTER 2

LITERATURE SURVEY

This chapter is composed of relevant information in literature regarding the matter of the study. It covers issues related to (1) sustainability in architecture, (2) relation of high-rise buildings and sustainability, (3) evolution of sustainable high-rise buildings, (4) definition, classification and development process of service core, and (5) bio-climatic approach to service core design. In the end, an evaluation of the literature survey is presented to summarize accumulated knowledge and to view the whole frame.

2.1 SUSTAINABILITY IN ARCHITECTURE

The reasons behind the sustainability movement began with the European industrial revolution in the 1700s (Vakili-Ardebili & Boussabaine, 2010). While changing the urban makeup and life styles of people, the industrial revolution also affected use of raw materials and amount of energy demand (Vakili-Ardebili & Boussabaine, 2010). Vakili-Ardebili & Boussabaine (2010) state that the consequent pollution and depletion of natural resources are accepted as environmental outcomes of the process. However, after a while, it started to affect the quality of life in a bad way rather than improving it, and caused to develop a conscious regarding sustainability (Vakili-Ardebili & Boussabaine, 2010).

The work of Bribian, Uson and Scarpellini (2009) notifies that the building sector has a great share in the global environmental load of human activities. According to Xing, Xu and Jun (2007: 1), “The ratio of building energy consumption in overall energy consumption of China is increasing year by year, which has increased from 10% at 1970s to 27,45% by now.” Edwards (1999) states that this growth causes the environmental problems in various ways. He claims that buildings are responsible for 50 per cent of overall energy consumption, 40 per cent of the overall raw material consumption, 50 per cent of overall consumption of harmful chemicals to ozone layer, 80 per cent of the overall loss of agricultural fields, and 50 per cent of overall water consumption.

The expression of 'sustainable architecture' is defined as a design approach that encourages acting responsively towards the environment (Beedle *et al.* 2007b). Beedle *et al.* (2007b: 641) notes that "Sustainable architecture is sometimes misunderstood as a romantic nostalgic to the past with its simple and unpolluted vernacular ways of living. On the contrary, sustainability is a clarion call for the adoption of a new way of thinking." Williamson, Radford & Bennetts (2003) define sustainable building design as a construction that brings together the aesthetic, ethical, scientific and the other aspects of nature, culture and technology.

After the first world oil crisis in 1973, Energy Saving Laws are offered in Germany. However, the problem about the high energy demand of building sector has started to be addressed on the global scale in the early 1990s (Gonçalves & Umakoshi, 2010) (Figure 2.1). Pollution, depletion of natural resources, global warming, and other side effects of construction sector concern and affect all over the world. Thus, countries has been discussing and trying to form common targets. The global target of 2050 which aim to reduce the energy consumption of buildings 80 per cent is an important step to prevent the problems (Gonçalves & Umakoshi, 2010). On the other hand, Gonçalves & Umakoshi (2010) notifies that there are still a lot of buildings that are being constructed with very little or no concern for low energy demand and environmental sensitivity in different parts of the world, especially in developing countries.

ENVIRONMENTAL TIMELINE

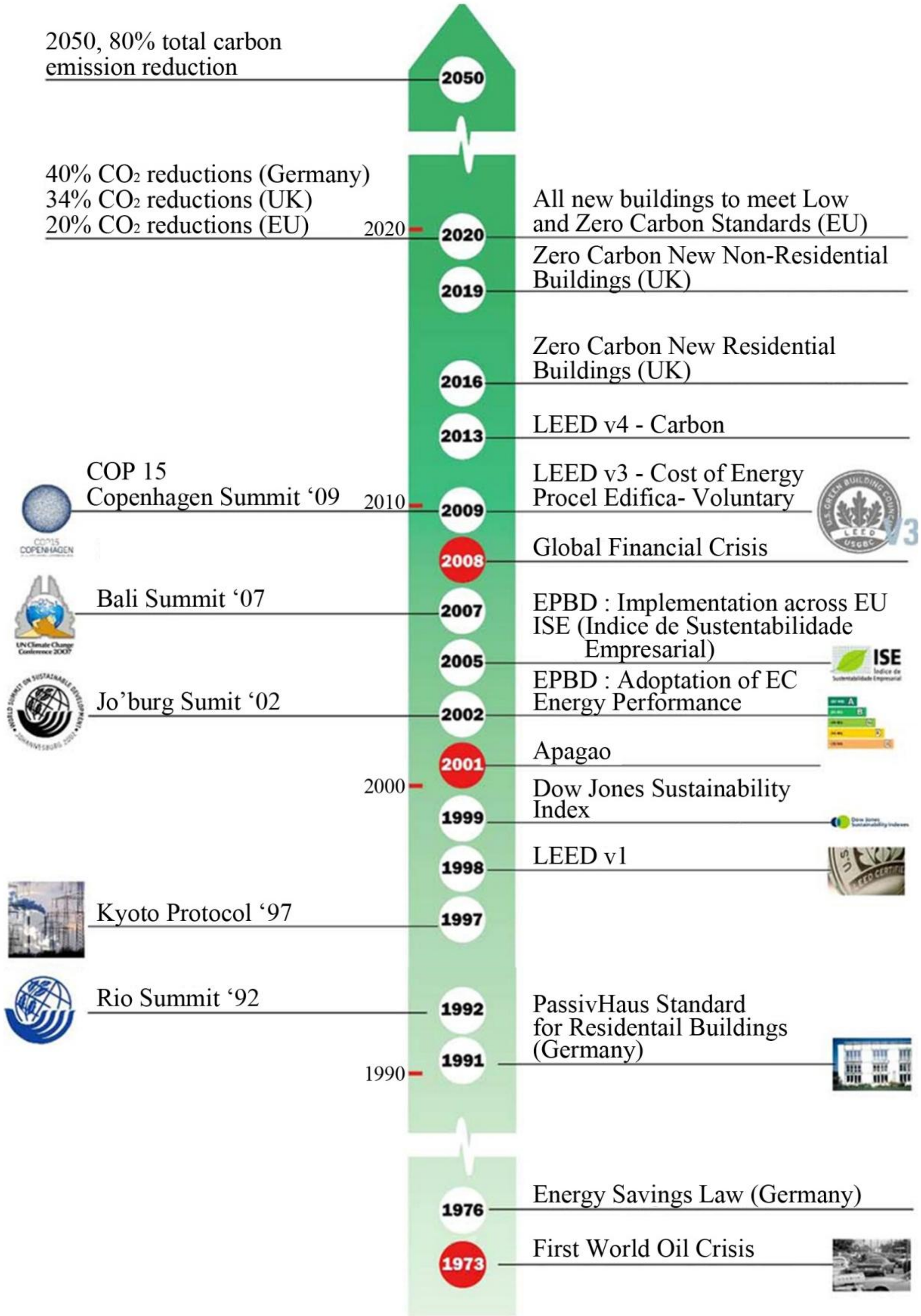


Figure 2.1. Environmental timeline (Source: Gonçalves & Umakoshi, 2010)

2.2 HIGH-RISE BUILDINGS AND SUSTAINABILITY

Cities are getting larger year by year. According to the United Nations' *Global Report on Human Settlements* (1996), 80 per cent of the world population will settled in urban areas in 2050 which correspond to 9 billion people. According to the report, it is expected that the major cities of the world will shelter huge populations, between 30 million and 50 million or maybe more. In the light of these projections, Gonçalves & Umakoshi (2010) declare high-rise buildings as the future cities' typology due to their optimization of land.

At first, European cities like Paris, London and Rome stood aloof from high-rise building typology, and introduce some height control regulations to protect their skylines (Beedle *et al.*, 2007a). However, today, these cities, especially Paris and London, started to adopt high-rise buildings in favor of their functional and symbolic advantages (Beedle *et al.*, 2007a).

Gonçalves & Umakoshi (2010) state that the globalization process has transformed the cities. Today, the cities are showing a similar design of high-rise buildings, especially in financial districts, which are quite far from being energy efficient sustainable designs (Gonçalves & Umakoshi, 2010). These typical 'glass box' buildings are copied from city to city as a symbol of power and prosperity (Wood, 2007). However, there are considerable climatic differences between the cities where high-rise buildings are located.

Because of the growing role of high-rise buildings in cities, designers who involve with the execution of high-rise buildings should be worked on to lower the energy demand of these typologies (Gonçalves & Umakoshi, 2010). Due to the great environmental impact of these buildings, the design of high-rise buildings should be revised critically in terms of climate, culture, economy and function to meet the global requirements of environmental sustainability (Gonçalves & Umakoshi, 2010).

2.2.1 Definition of High-Rise Building

With the use of steel frame in the building constructions, and the invention of elevator in 1853, buildings passed the limit of five stories (Gonçalves & Umakoshi, 2010). The 12-storey, 55m high Home Insurance Building, built in Chicago in 1885 is recognised as being the first skyscraper (Günel & Ilgın, 2010). With the technological innovations in the beginning of the 20th century, buildings reached up to 20 stories, which is considered as the minimum height limit to define tallness in North America and Europe for decades (Gonçalves & Umakoshi, 2010). However, the latest definition of the Council on Tall Buildings and Urban Habitat (CTBUH) ("Ctbuh height criteria," 2011) clarifies that tallness cannot be defined just by a height limit. CTBUH considers three important parameters: the relative height among the urban fabric, height to width proportion of the building and technology used in the building which is affected by the aspects of tallness.

In urban terms, tallness depends on the overall category of the surrounding buildings in terms of height (Gonçalves & Umakoshi, 2010). For example, while a 100-storey skyscraper remains an ordinary building in Manhattan district, a five-storey building located in a one-storey neighborhood can be accepted as a high-rise building. Similarly, while number of the floors in New York and Chicago are typically 40 and 60, respectively, there is a limited number of buildings over 40 floors in Europe (Gonçalves & Umakoshi, 2010).

Form of a building is another criteria defining tallness. For a structural engineer, height-to-with ratio of a building which is also referred as aspect ratio or slenderness is more critical than its height (Gonçalves & Umakoshi, 2010). By the same token, the slenderness of a building leads to special treatment for vertical circulation strategies, floor plate design and technology used for services (Gonçalves & Umakoshi, 2010). Aspect ratio or slenderness ranges from 5:1 to 11:1 for high-rise buildings (Taranath, 2005; Zils & Viise, 2003). However, the ratio of 8:1 is the most typical and feasible value (Taranath, 2005; Zils & Viise, 2003).

2.2.2 High-Rise Building Typology- Sustainable or not

Since the environmental concern arose, the impact of high-rise buildings has been questioned (Beedle *et al.*, 2007b). There are conflicting ideas on this issue. There are those who believe that high-rise building typology has a great potential to provide solutions for environmental problems (Beedle *et al.*, 2007b). Beedle *et al.* (2007b) note that high-rise buildings occupy smaller footprint area which enables open spaces such as parks, plazas and other community areas (Figure 2.2). They add that this building typology can prevent the urban sprawl due to the compactness of the city. To quote Beedle *et al.* (2007a: 149), "the spreading suburbs require a successively growing network of transportation and other urban services, eventually reaching a limit. The time, cost and energy consumption do not justify the continued spread." Additionally, this compactness of the city lowers the transportation costs, and enables other means of transportation possibilities such as walking or cycling (Gonçalves & Umakoshi, 2010). However, Gonçalves & Umakoshi (2010) notes that if a sufficient urban infrastructure is not provided, this centralization of the city will generate traffic congestion, and turns an advantage to a disadvantage.

Opposite to the general belief, the cities having more than one million population have smaller metabolic flow rates than smaller cities per capita when water and energy consumption, land inputs, and waste outputs are considered (Newman, 2001). The reason of the reduction in the rates is coming from "the economics of scale and density, producing greater efficiency in technology, more access to markets for recycling , better public transport, and a generally more efficient use of land" (Beedle *et al.*, 2007b: 674). By the same token, a high-rise building shows a smaller metabolic flow than a low-rise building due to the similar reasons (Beedle *et al.*, 2007b).

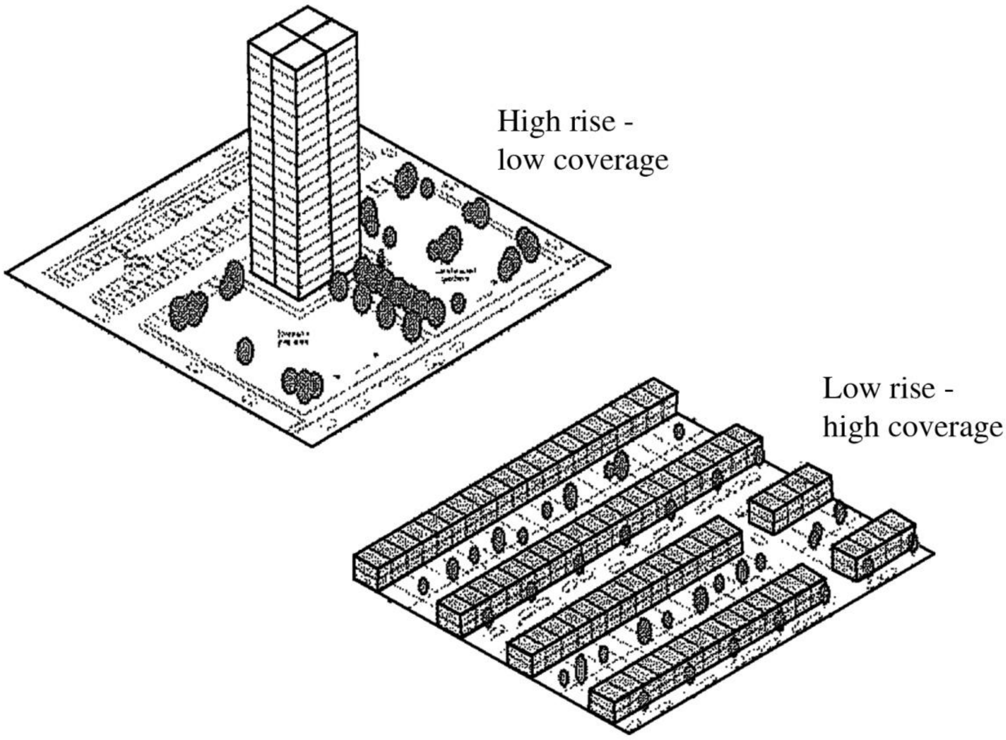


Figure 2.2. Alternatives for massing of buildings based on the same density (Source: Gonçalves & Umakoshi, 2010)

The graph of Newman and Kenworthy (1989) shows the relationship between density and gasoline consumption per person in 32 cities over the world (Figure 2.3). It can be observed that the cities having clusters of high-rise buildings, such as Singapore and Hong Kong, consume energy for transportation much more less than the cities with great urban sprawl such as Los Angeles and Houston. New York which is known as to host well-known high-rise buildings is not shown as an efficient city in the graph. This outcome results from the fact that the study behind the graph includes the total area of the city, rather than just the Manhattan Island where the high-rise buildings are located (Gonçalves & Umakoshi, 2010).

In the opposite way, there are those who consider high-rise buildings as anti-environmental typologies. Beedle *et al*. (2007b) take attention to the huge

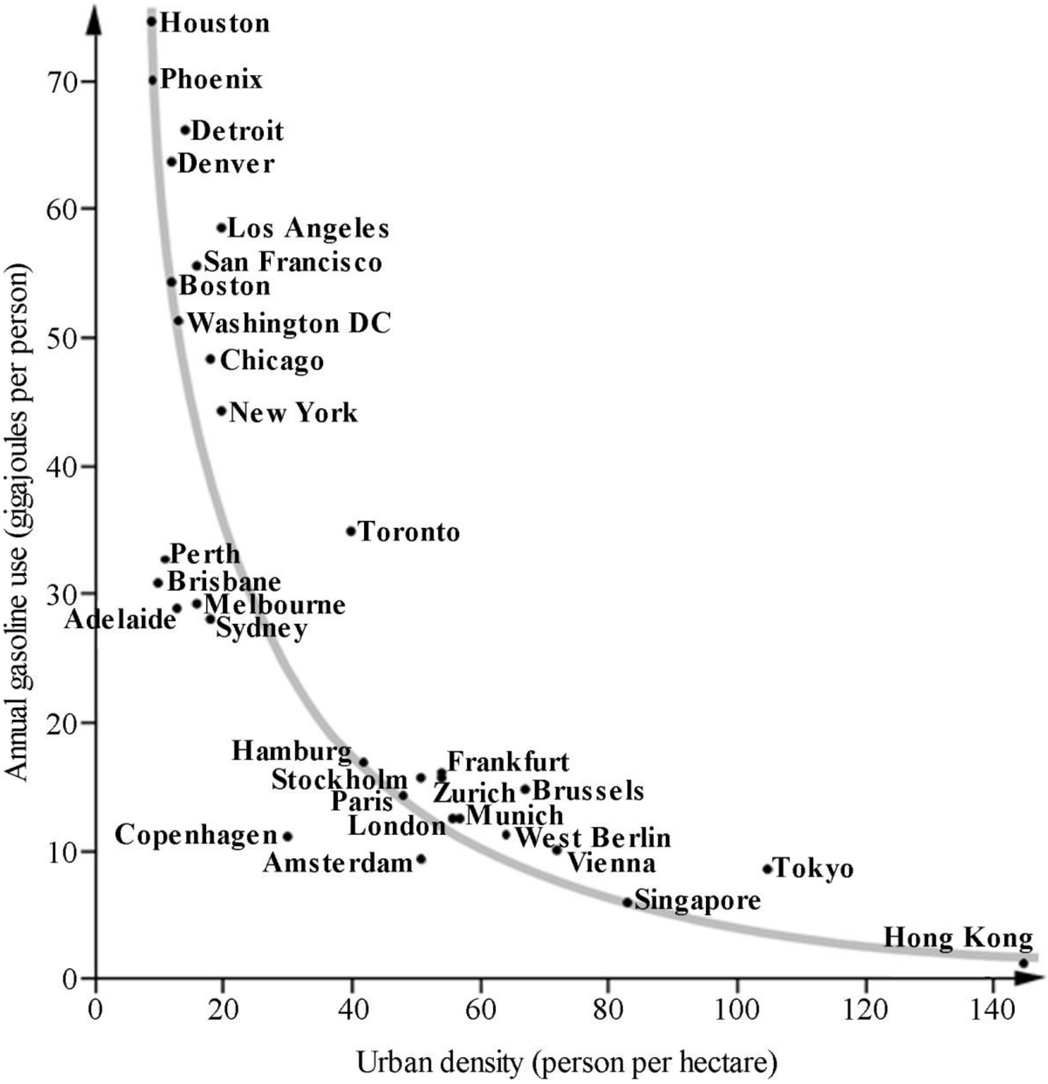


Figure 2.3. The relationship between density and gasoline consumption per person in 32 cities (Source: Gonçalves & Umakoshi, 2010)

amounts of energy consumed for the operation of the high-rise buildings while adding the negative social effects of them within the surrounding fabric such as lack of mutual trust and community feeling. Another criticism on the issue is about the construction cost of a high-rise building. Because of the huge weight and the large magnitude of wind forces, the structure of a high-rise building costs more than of a low-rise building (Beedle *et al.*, 2007a). Above from the amount of material used in the process, the special technologies used to build up the building cause a significant increase in price (Gonçalves & Umakoshi, 2010). Yeang & Powell (2007) claim that when compared to other building typologies, high-rise buildings consumes at least three times more energy and material to construct, to run and to demolish.

In fact, Gonçalves & Umakoshi (2010) who admit the higher demand of the high-rise buildings, associate these problems with the design approach, not the typology. To quote them (2010: 210):

> Often the common criticism of energy consumption associated with tall buildings takes as a reference the conventional commercial architectural design of the square box with central core, sealed glass façade and deep and repeatable floor plates. In this case, the tall building would inevitably consume significant amount of energy, however, the problem is associated with the design approach and not with the problems inherent in the typology or the height of the building.

Gonçalves & Umakoshi (2010) believe that if the design of a high-rise building has been properly worked on, the inherent advantages of the typology can offset the disadvantages. For example, the energy demand of vertical transportation of a high-rise building has a significant share over the total demand (Gonçalves & Umakoshi, 2010). This vertical movement can be classified into two groups: (1) enter to and exit from the building, and (2) travel between floors for intercompany activities (Gonçalves & Umakoshi, 2010). For the first group, the designers can adopt 'sky-lobby' concept in which the building is separated into zones, and the elevators serve as groups to each zone while interconnected by transfer floors (Yeang, 1996). Additionally, elevators can be grouped as one on the top of other as dual or triple configurations (Yeang, 1999). These measures will reduce the energy demand while increasing the net usable area (Yeang, 1996).

The second group in the vertical traffic is movement between the floors. Commercial high-rise buildings generally accommodate the companies that are occupying more than one floor (Gonçalves & Umakoshi, 2010). The movements within the company departments are generally more frequent than the entry or exit movements (Gonçalves & Umakoshi, 2010). In that sense, an alternative staircase can be located between these floors to diminish the elevator use as in the case of New York Times Tower designed by FXFOWLE and Renzo Piano Building Workshop in 2007 (Fact Sheet, 2007).

2.3 EVOLUTION OF SUSTAINABLE HIGH-RISE BUILDINGS

In the 1950s, the design strategy for buildings was to maximize the natural light and ventilation due to the lack of developed air conditioning and lighting systems (Cho, 2005). However, along with the increased equipment reliability and technical innovations, mechanically controlled and sealed buildings emerged (Cho, 2005). These buildings provide indoor comfort conditions dependant on the mechanical systems by using great amount of non-renewable energy, and the energy performance of a building was at the end of the design consideration list due to the relatively inexpensive energy supply (Cho, 2005).

After the energy crisis in 1970s, a conscious movement emerged towards the reduction in energy consumption and independency on non-renewable oil supply (Beedle *et al*., 2007b). With the introduction of this movement, there occurred different ideas questioning sustainability of high-rise buildings (Wood, 2007). However, many builders and land owners, above all this debate, continue to want the standard type air-conditioned glass boxes (Wood, 2007). This style appeared on the scene in 1970s with the movement called Modernism by Walter Gropius, Mies van der Rohe, Le Corbusier, etc., and widely accepted as the high-rise building typology (Beedle *et al*., 2007a).

Because of the portable nature of these unrooted and non-site-specific building types, they have mushroomed all over the world without any respect for their effect on environment or accordance with the place they are located (Powell & Yeang, 2007). According to Wood (2007), the growth of these typical high-rise buildings is harming the nature both locally and globally. Especially, developing countries show examples of this situation (Wood, 2007). They present a great similarity with their western equivalents by importing the rectangular glass box type high-rise buildings (Wood, 2007).

Wood (2007) states that, there have been some efforts to localize the high-rise buildings in the developing countries. However, they were not radical changes but some abstracted forms from local philosophies or religions that were used in design of the buildings. Moreover, the architectural language of cladding and curtain wall was totally western (Wood, 2007).

Eventually, with an increased conscious about the detrimental effect of high-rise buildings on environment, architects and engineers have started to work on sustainability of them (Elnimeiri & Gupta, 2008). By the last two decades, there have occurred a small but growing group of professionals who searches for a proper way for high-rise buildings to compensate or decrease the embodied energy demand of them (Wood, 2007). They work on to localize the buildings to fit to time and place where they are going to be built (Wood, 2007).

2.3.1 The Rise of Environmental Conscious in High-Rise Building Design

Interestingly, the first idea about sustainable high-rise buildings was from Frank Lloyd Wright in the mid 1950s (Wood, 2007). Lloyd Wright, by leaving from most of his colleagues, believed that high-rise buildings should not be a part of city, but a sculptural element in rural landscape (Wood, 2007). According to Wood (2007), Lloyd Wright's vision is to prevent loss of green areas and suburban sprawl by gathering lots of people together on a smaller plot. In those times, his ideas were too radical, so the 1956 Prize Tower at Oklahoma, USA was the only building he could realized (Figure 2.4) (Wood, 2007). Wood (2007) notifies that, this building applied some of sustainable features such as; (1) rejection of glass curtain walls and using large solid façades due to optimize solar gain and insulation; (2) using external louvers to control light and temperature; (3) applying a mix-use function of office and residential space which is termed as social sustainability.

The energy crises in 1973 and the sick building syndrome (SBS) of the buildings resulted from the bad quality air conditioned environments make designers look for an alternative strategy (Gonçalves & Umakoshi, 2010). Although this is not

Figure 2.4. Price Tower, 1956, Oklahoma
(Source: Wood, 2007)

directly related to the 'glass-box' typology, such movements provide an opportunity to review the current design trend of high-rise buildings (Gonçalves & Umakoshi, 2010). Along with these developments, the deep floor plate configurations, mechanically controlled environments, and energy expensive systems are criticized (Gonçalves & Umakoshi, 2010). As a consequence, sustainable high-rise buildings which are offered more climate-responsive designs started to be built towards the end of the 1980s (Gonçalves & Umakoshi, 2010).

Skidmore Owings & Merrill (SOM) built one of the first sustainable high-rise buildings, which has a completely environmental approach, in 1984 (Wood, 2007). National Commercial Bank (Figure 2.5), which is located in hot desert climate of Jeddah, applied an opaque façade to get rid of excessive solar gain. The light for occupants is obtained from a glass curtain wall at the internal part of the

Figure 2.5. National Commercial Bank, 1984, Jeddah
(Source: Google Images)

building and from consciously positioned sky gardens (Wood, 2007). As Wood (2007: 404) notes;

> Although the aesthetic of the austere, monolithic stone block presented to outside of the building is not to the liking of some, this introverted glass façade design strategy undoubtedly makes more sense environmentally than an external curtain glass wall in such a hot climate and ... gives the building an aesthetic that firmly roots the building in both its desert locale and cultural context.

Some other environmental high-rise buildings have been built within the scope of Islamic culture such as 1993 Islamic Development Bank of Nikken Sekkei and 1994 Dayabumi Complex of BEP Architect's in Kuala Lumpur (Figure 2.6) (Wood, 2007). In Dayabumi Complex, a stone façade which is forming an Islamic pattern has been applied to provide a protection from excessive solar gain. This system is not only one of first uses of double-skin façade, but also an important application of sustainable strategies in hot climates (Wood, 2007).

In Malaysia, Ken Yeang developed a completely different approach to reach sustainability in high-rise buildings (Yeang, 1996). Different than Dayabumi Complex which achieving sustainability and localization by using components decorated by local culture, Yeang rejected cultural inspirations and advocates 'eco-mimicry' in his terms (Yeang, 2006) . To quote Yeang (1996: 21);

> Of course, we must be aware that besides climatic criteria, there are many other criteria for design, such as economics, culture, building program, site contours, views, etc. However, a locality's climate is probably its most durably endemic characteristic.

Figure 2.6. Dayabumi Complex, 1994, Kuala Lumpur
(Source: Google Images)

> As the location's most endemic factor, climate provides the designer with a legitimate starting point for architectural expression in the endeavor to design in relation to place, because climate is one of the dominant determinants of the local inhabitant's lifestyle and landscape's ecology.

To form and orient high-rise buildings with respect to sun and wind like Yeang, serve to control solar gain, and provide passive ventilation (Yeang, 1996). Although the project has not been realized, the 1995 Tokyo-Nara Tower (Figure 2.7) presents the potential of Yeang's ideas in the best way (Wood, 2007). The project combined continual landscaping, flexible form and embedded environmental technologies which, as Wood (2007: 405) states, “has created a vernacular expression which is at the extreme end of the potential aesthetic for the environmental skyscraper."

Norman Foster has, also, designed environmental skyscrapers but uses a different material palette than Yeang (Wood, 2007). Foster's designs are not very far from standard Western high-rises in terms of utilization of steel and glass (Wood, 2007) but he notched up some of the best environmental high-rise buildings like 1997 Commerzbank Frankfurt, 2003 Swiss Re Tower and 2006 Hearst Tower New York (Figure 2.8) (Wood, 2007). Wood (2007) notifies that, works of Yeang and Foster summarize the controversy on possible future high-rise buildings as being green or grey.

Figure 2.7. Tokyo-Nara Tower, 1995, Tokyo
(Source: Google Images)

2.3.2 Contemporary Environmental High-Rise Buildings

Contemporarily, technological innovations have become the key point for obtaining sustainable high-rise buildings (Wood, 2007). These technologies not only avail harvesting energy at height or provide ventilation, but also form an aesthetical expression through highlighting these gadgets like photovoltaic panels or wind turbines (Wood, 2007). Along with the technological components, acceptance of a reduction in comfort levels constitutes another step for sustainable design (Beedle *et al.*, 2007b). In this respect, the Government of Hong Kong lowered the indoor temperature of government offices at or above 25.5˚C to reduce the energy demand of the buildings (Yıu-Ching, 2005).

Figure 2.8. Hearst Tower, 2006, New York
(Source: Google Images)

One of the best examples of this generation is Atkins' Bahrain World Trade Centre (Figure 2.9) with its gigantic wind turbines forming the most prominent component in the architectural outlook (Wood, 2007). Although there are successful examples like Bahrain World Trade Centre, many of these sustainable technologies are misled (Powell & Yeang, 2007). In fact, There is a misperception as if there is enough eco-gadgetry such as wind turbines, photovoltaic panels, ground source heat pumps and automation systems applied, that building would eventually be sustainable (Powell & Yeang, 2007). However, many of these technologies are applied to standard model air conditioned boxes, and there are much more significant sustainability errors such as building orientation and shape (Wood, 2007).

Figure 2.9. Bahrain World Trade Centre, 2008,
Bahrain (Source: Google Images)

Gonçalves & Umakoshi (2010), also, notifies the misapplications about environmental strategies of high-rise buildings around the world. They note that introduction of isolated green applications affects the total energy demand of buildings insignificantly, and becoming small architectural ornamentations. For instance, the buildings with double glazed or double-skin façades are presented as 'green'; however, this design strategy is not enough to lower the energy consumption tangibly due to the high level of heat transmission through the over-glazed façades with no shading (Gonçalves & Umakoshi, 2010).

There are a group of high-rise buildings that provide a different environmental language beyond the high-tech glass box (Wood, 2007). Ken Shuttleworth of Make Architects in UK has proposed provocative high-rise buildings that present a greater opacity in the façade with a different language (Wood, 2007). To quote Shuttleworth (2005: 1),

> The high-energy, gas-guzzling fully glazed office block is totally dead, a thing from a previous time when we all had a more naive, cavalier attitude towards the environment ... It's the end of an era and we should all rethink what we are doing to the planet ... façade design is on the frontline of a change.

Vortex Tower (2004), Kite Tower (2004), and Spiracle Tower (2005) (Figure 2.10) are some of Shuttleworth's proposals (Wood, 2007). In Spiracle Tower, panels are applied in the form of undulating horizontal bands which control the solar gain. The rippling effect of this external skin is determined according to the function of the interior spaces, which the paneling extending downwards to create glazing slots for bedrooms and opening up to enable views out from balconies that lead into living spaces (Make Architects, 2005).

The most recent examples of sustainable high-rise buildings combine standard model and environmental technologies in a more functional and elegant way

(Wood, 2007). One of the best examples is COR Tower (2007) (Figure 2.11) with its well balanced transparent-opaque skin and wind turbines blend in the skin of the building (Wood, 2007). According to Wood (2007), this design strategy is the way for successful environmental high-rise buildings which satisfies needs of both sustainability and appearance.

2.3.3 Eco-Labeling

In early 1990s, some kind of rating systems, generally as called of building environmental assessment methods (BEAMs), emerged to assess the 'greenness' of buildings (Yıu-Ching, 2005). Operation system of these methods depends on giving points to each relevant aspect, and concluding with an overall score to label

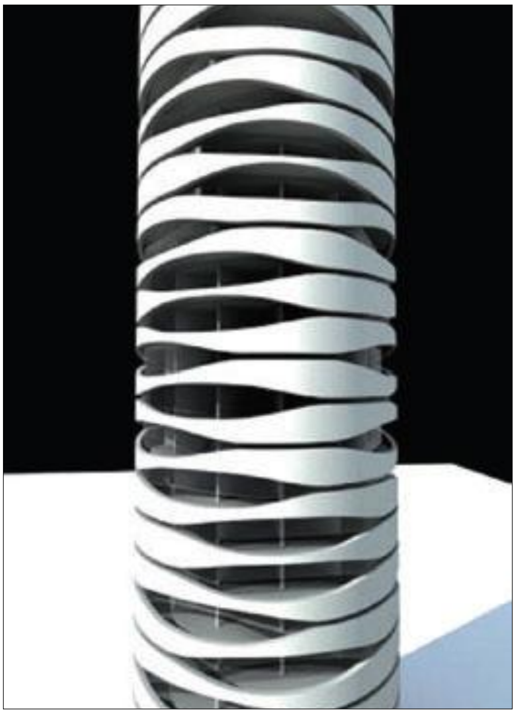


Figure 2.10. Spiracle Tower
(Source: http://www.makearchitects.com)

Figure 2.11. COR Tower, Miami
(Source: http://www.inhabitat.com)

the sustainability level of the related building (Table 2.1) (Yıu-Ching, 2005). The assessment criteria or the percentage of a criterion may vary for different BEAMs. For instance, while the United Kingdom uses the Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy & Environmental Design (LEED) is the general assessment method used in the United States (US) (Yıu-Ching, 2005). The others are: Green Star in Australia; German Sustainable Building Certification in Germany; Comprehensive Assessment System for Building Environment Efficiency (CASBEE) in Japan; Green Star SA in South Africa; and Green Star NZ in New Zeland (Sillah, 2010).

Buildings which are labeled as ‘BREEAM-Excellent’ or ‘LEED-Gold' are revealed as green buildings. However, Burnett (2005) states that this measure of green would change with the environmental issues covered by the BEAM and percentages of them. He adds that some issues about success of the methods are under discussion such as: the extent to which assessment is based on actual measurements, check-lists, simulation, performance based or feature specific, etc. Gonçalves & Umakoshi (2010: 24) note that "with regard to energy performance, the subject of energy demand reduction and supply generation are not rated in equitable terms and nor do they consider the difficulty of increasingly reducing demand." Additionally, these methods give more shares to building services than architectural design solutions which are the core of the sustainability issue (Gonçalves & Umakoshi, 2010).

2.3.4 Future High-Rise Buildings

What will the high-rise buildings of the future look like? Getting higher and higher is not a new phenomenon. According to the studies, by the year 2030, two-thirds of people will live in urban centers (Beedle *et al.*, 2007a). Thus, sheltering large populations while providing a better welfare level will be the future strategy for high-rise buildings (Beedle *et al.*, 2007a). Beedle *et al.* state that, this situation will cause more 'cities in the sky' or 'vertical cities' in which there will be working, living and playing areas.

Japan's Takenaka Company proposed high-rises of future that are connected to each other while providing enough open green space (Beedle *et al.*, 2007a). One of them is the Sky City 1000 ("Tokyo's sky city," 2012) (Figure 2.12). The project is proposed to shelter 36,000 residents and 100,000 workers ("Tokyo's sky city," 2012). The building is 400 m wide at the base, and is designed as a place where people could theoretically live their whole lives. The Holonic Tower is another visionary project of the company planning 500-year working life (Beedle *et al.*, 2007a). With extensive green areas, advanced energy conservation systems, and developed social facilities, it is designed as a complete sustainable high-rise building of the future (Beedle *et al.*, 2007a). The trend to apply one design

Table 2.1. Building environmental assessment methods (BEAMs)

BEAM	Grouping of issues	Points/credits	Award levels	Assessments
Initial launch 1991. BREEAM 98 for offices (Ref: 2005 checklist for new buildings	Management Health/Well-being Energy Transport Water Materials Land Use Ecology Pollution	160 Pts (16 %) 150 Pts (15 %) 136 Pts (14 %) 98Pts (10 %) 48 Pts (5 %) 88 Pts (9 %) 30 Pts (3 %) 126 Pts (13 %) 144 Pts (15 %)	Pass = 253 Pts (24 %) Good = 385 Pts (39 %) Very Good = 530 Pts (54 %) Excellent = 675 Pts (69 %)	25% of new buildings for prior version BREEAM for offices - estimated 260 projects for BREEAM 98 for offices
Initial launch 1996. Ref: HK-BEAM 4/04 New Buildings (data assumes office building)	Site Aspects Material Aspects Energy Use Water Use IEQ (Sustainable issues) Innovation	25 credits (21 %) 20 credits (17 %) 29 credits (25 %) 12 credits (10 %) 32 credits (27 %) (7 credits) 5 bonus credits	Bronze = 40 % Silver = 55 % Gold = 65 % Platinum = 75 %	All versions from 1/96 (1996) to 4/04 (2004) - total 100 new and existing residential and commercial buildings
Initial launch 2000. Ref: LEED NC 2.1 (November 2003	Sustainable Sites Water Efficiency Energy/Atmosphere Material/Resource IEQ Innovation	1 Pre + 14 Pts (20 %) 5 Pts (7 %) 3 Pre + 17 Pts (25 %) 1 Pre + 13 Pts (19 %) 2 Pre + 15 Pts (22 %) 5 Pts (7 %)	Certified = 26 Pts (38 %) Silver = 33 Pts (48 %) Gold = 39 Pts (57 %) Platinum = 52 Pts (75 %)	Including version 2.0 - around 180 certified projects and 1800 registered projects

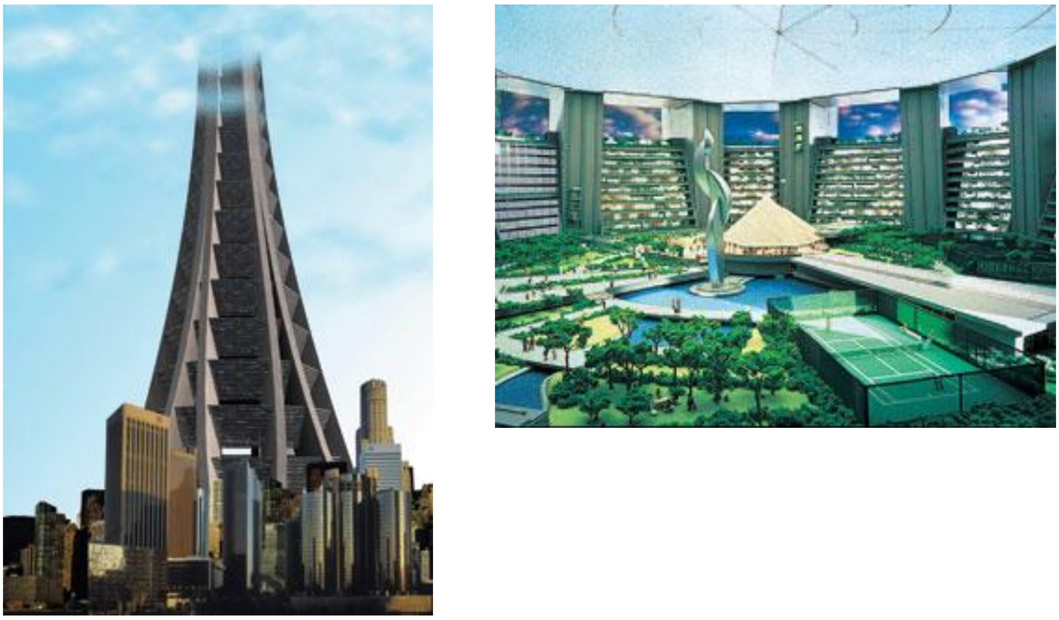


Figure 2.12. Sky City 1000, Japan (Source: Google Images)

scheme all over the world is over. The future sustainable high-rise buildings will not be identical but, will be composition of fragmented ideas and the needs of the time (Beedle *et al.*, 2007a).

2.4 SERVICE CORE

It is impossible to use every square meter of a high-rise building for the function of the building built for (Trabucco, 2008). The reason is that every function of the building requires some services and facilities to run, to access or to endure (Trabucco, 2008). The space required for these services and facilities differs with type, height and function of the building (Yeang, 2000). Consequently, the gross floor area (GFA) of a high-rise building can be divided into two sections: the area which is used for function of the building and the area serves to the first (Trabucco, 2008). The efficient area which is the saleable or rentable part of the building is called the Net Floor Area (NFA) and the latter is called as service core (Yeang, 2000).

2.4.1 Definition

Basically, a service core is a compact space which consists of elevators, elevator shafts, elevator lobbies, fire-protected lobbies, staircases, vertical M&E services, ducts, water pipes, toilets, air handling units, etc. (Yeang, 2000). Because of accessibility, ease of keeping in use and some economic reasons, these components of a high-rise building are always clustered and formed a vertical stem linking the floors (Trabucco, 2010).

Particularly, a service core can contribute to high-rise buildings as the primary structural element for both vertical (gravity) and lateral (wind, earthquake) load-resisting systems (Yeang, 2000). Due to the detrimental effect of wind on high-rise buildings, the service core can be used to provide stiffness, and decrease the top deflection of the building to between the permitted limits (Yeang, 2000).

Thus, according to Trabucco (2008), a service core is composed of the following:

1. Services: basically includes staircases and elevator shafts with cars. Elevators can be for people, goods or vehicles. Moreover, staircases can be divided as main and emergency. However, to maximize the NFA, all the staircases are design as fire escapes at most of the time. The other services are toilets, fire-protected lobbies, elevator lobbies, and sometimes pantry.

2. Subservices: basically includes electrical cables, risers for telecommunication and data systems, risers for sprinkler systems, sewer age pipes, rainwater pipes, hot water pipes, and exhaust ducts. Generally,

they are placed after the major utilities like elevator, because they take a smaller area than the others.

3. Core: the shell which is either structural or nonstructural that surrounds the services. The structural core is used when the structural system of the building consists of shear wall/bracings to withstand the loads; otherwise, it can be omitted.

2.4.2 Classification of Service Cores

Service cores are basically classified as central/internal and peripheral/external (Trabucco, 2010). Although there are other classifications, Yeang (2000) and Beedle *et al*. (2007a) classify service cores regarding the placement as four generic types of arrangements. They are (Figure 2.13):

- the central core
- the split core
- the end core
- the atrium core

In this dissertation, three service core types are examined which are the central core, the split core and the end core. Throughout the study, both the split and end core types are also referred as the peripheral or the external service cores as an abridgment.

The selection of the best configuration for a particular building differs with the function of the building, fire regulations and building codes of the related country, climatic conditions, personal design choices, etc. (Yeang, 2000). Vertical circulation system depends on the relation between the service core type and the usable areas in floor plan configuration (Beedle *et al.*, 2007a). Selecting the appropriate arrangement would help to find solution for the objectives of the building (Yeang, 2000). For example, if the main objective of the design is a clear internal space, then the end core configuration may be the most efficient solution if the fire escape distances remain between the fire regulation limits (Yeang, 2000). As another example, if there is a consideration as designing a sustainable high-rise building, the split core arrangement could provide a better low-energy performance (Yeang, 2000).

The placement of the core also depends on the tenancy conditions (Yeang, 2000). While single-tenant condition is the most flexible to decide, for multi-tenant situations there should be selected a service core type that could provide service for all of the tenants (Yeang, 2000).

2.4.3 Development of Service Cores through History

After the erection of the "first skyscraper", The Home Insurance Building, in Chicago in 1885, this typology spread throughout the world, and become an indication of power (Oldfield, Trabucco & Wood, 2009). From 1885 to now, the high-rise typology has changed and evolved due to regulatory changes, advancements in technology, increased material alternatives, and change in architectural thinking and economy (Oldfield *et al*., 2009). As the high-rise typology, the service core of today has undergone a number of shifts, and is still evolving (Trabucco, 2010). The work of Oldfield *et al.* (2009) divides the evolution of high-rise buildings in five sections regarding the characteristics of energy consumption. The development of service cores cannot be thought as a separate part of these five processes which are presented in the following sections.

2.4.3.1 From the birth to 1916 Zoning Law

Since the beginning of building activity, a person's limit to climb has restricted the height of the buildings (Yeang, 1996). In the late 19th century, the invention of

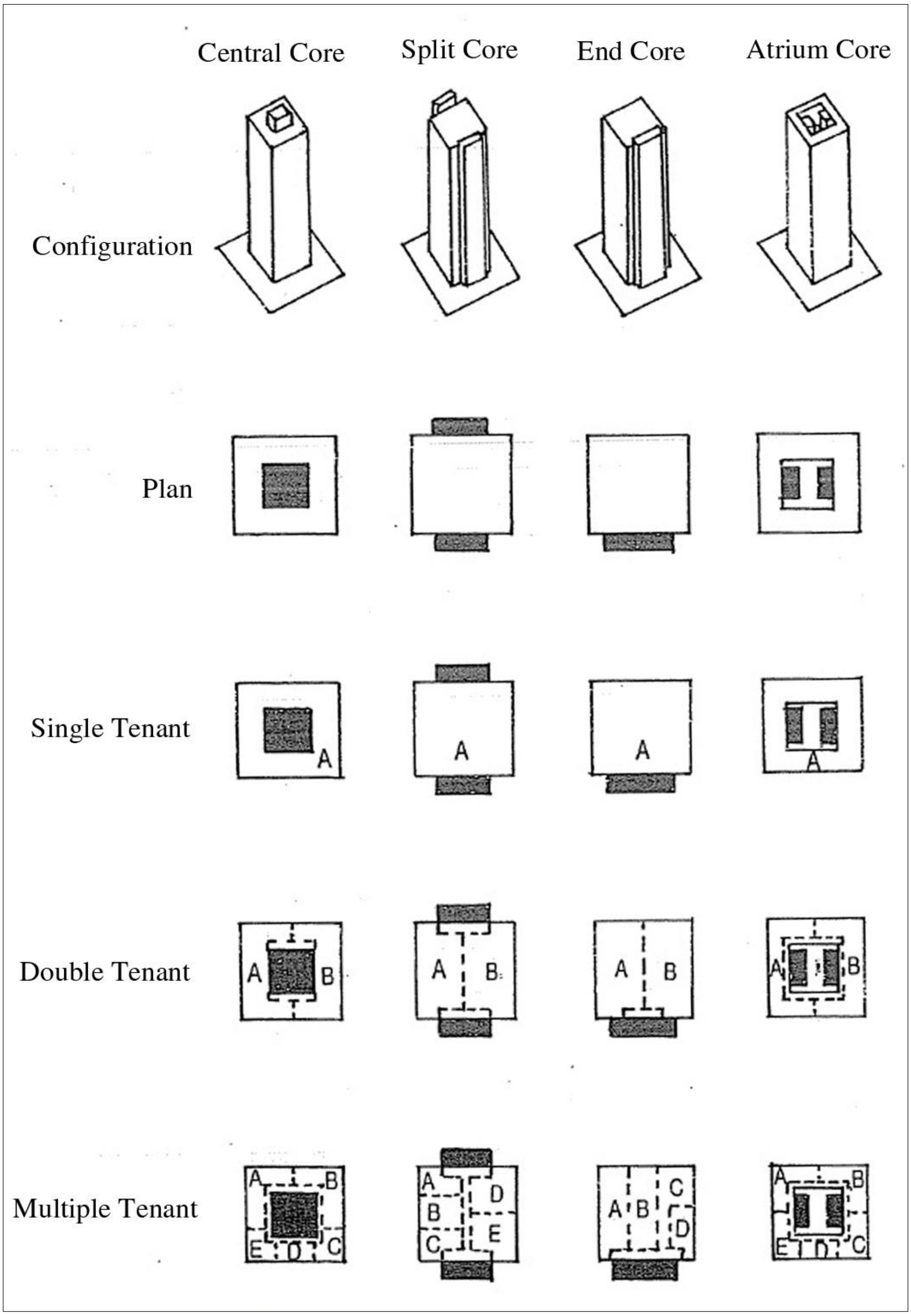


Figure 2.13. The arrangement of generic service core types
(Source: Yeang, 2000)

elevators and steel construction systems -in replacement of masonry- has enabled higher buildings (Günel & Ilgın, 2010). After the erection of 12-storey Home Insurance Building in 1885, two American cities, New York and Chicago, experienced the initial high-rise buildings where today's compact and specified service core did not exist (Trabucco, 2010). Maximizing the natural light and optimizing the land area were the two main objectives of the high-rise building designs (Trabucco, 2010). Artificial lighting -meant electric and gas lamps in those years- did not provide efficient lighting, and this situation led the elevator shafts and other service facilities on the dark and the least valuable places (Trabucco, 2010). To receive natural light all around the perimeter, service facilities were located at the centre of the buildings which was also an effective configuration to provide service for multiple tenants (Trabucco, 2010).

New York - The arrangement of buildings was determined by the lot sizes which were 20 to 30 meters in wide and 60 to 70 meters in depth (Trabucco, 2010). Buildings were located on full or half of a block, but, in both cases elevator shafts were placed in the centre due to getting as much as natural light along the façade for activity areas (Trabucco, 2010). In the case of full-block examples, elevators up to 12 to 14 cars aligned in a row as seen in Figure 2.14. In the second case, there was a central hall about 2.5 meters wide which was flanked by another 2.5 meters by elevators (Trabucco, 2010). This central hall had provided access to the offices located around the perimeter to maximize the natural light (Trabucco, 2010). In both cases, the centrally located elevator shafts did not contribute to the structural system (Trabucco, 2010). The other service facilities such as restrooms, electrical closets and vertical ducts were generally located in a peripheral position to provide ventilation (Trabucco, 2010).

Chicago - The grid of the city was 100 x 100 meters wide which led the massive 50 x 50 meters quarter blocks with the contribution of height regulation in Chicago (Trabucco, 2010). To increase the number of offices and provide natural light to deep volume, buildings had a huge light well (Figure 2.15) (Trabucco,

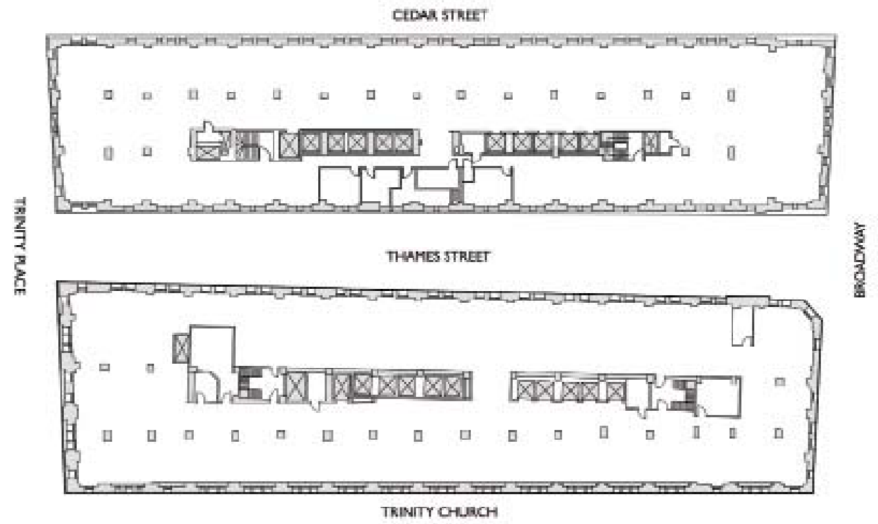


Figure 2.14. The Trinity and the US Reality Buildings, New York
(Source: Trabucco, 2010)

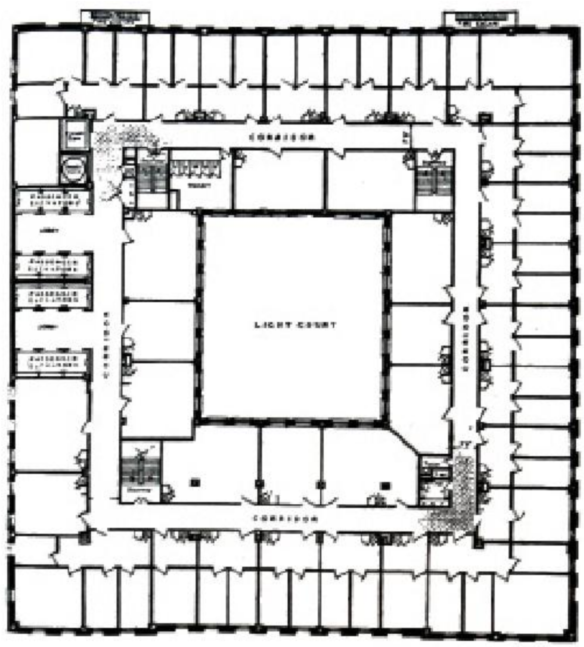


Figure 2.15. Straus Building, Chicago.
(Source: Trabucco, 2010)

2010). In this configuration, more estimable offices were located at the perimeter ring and the other ones faced the inner atrium (Trabucco, 2010). Therefore, the elevator system had to be in an offset position from the centre. The elevator shafts were generally grouped in two or four rows, and attached to a perimeter wall (Trabucco, 2010). If a building was erected in the adjacent lot, the adjacent offices of the existent building would turn to blind spaces. Thus, to decrease the possible dark rooms, elevator shafts were located in this configuration (Trabucco, 2010). This plan configuration caused some offices to be far from the elevators. To provide an efficient inter-floor communication, staircases were provided and located at the corners of the inner ring. In this way, inner transportation traffic was divided, and staircases formed the possible fire egress of the buildings (Trabucco, 2010).

2.4.3.2 The 1916 Zoning Law

Because of the lack of a planning regulation, massive stretched-to-lot high-rise buildings increased in number, and caused the problem of blocking sunlight and air flow (Oldfield *et al*., 2009). This situation let the New York authorities to restrict the bulk of buildings, and allow limitless height on 25 per cent of a building lot (Oldfield *et al*., 2009). Thus, the law resulted with buildings having set-backs by reducing the plan areas towards top (Trabucco, 2010). Those resulting set-backs made this prototype to be called as 'wedding cake' (Figure 2.16) and the most famous examples are the Empire State and Chrysler buildings in New York (Oldfield *et al*., 2009).

The service core configuration got its compact form in this generation. To provide service to all of the floors of this pyramidal shape, elevators, staircases and other services were located generally at the center as a group (Trabucco, 2010). However, still the service core was not a part of the structural system, and it could change place when the lot size was too small to place it in the centre (Oldfield *et al*., 2009).

2.4.3.3 After World War II

In the early 1950s, the innovation of glass curtain wall carried the wedding cake to the modern building image that has spread all over the world regardless of site and climate (Willis, 1995). Oldfield *et al*. (2009: 596) state that "Whereas tall buildings completed prior to the war, had between 20% and 40% glazing within their façades, 'third generation' buildings had a significantly higher ratio, between 50% and 75%". These rectangular glass boxes became the symbol of power and pride (Oldfield *et al*., 2009). However, there occurred some problems due to the huge glass surfaces such as excessive heat loss in winter and vice-versa in summer (Trabucco, 2010). As a result, air conditioning became the major energy usage requiring large ventilation ducts (Oldfield *et al.* 2009).

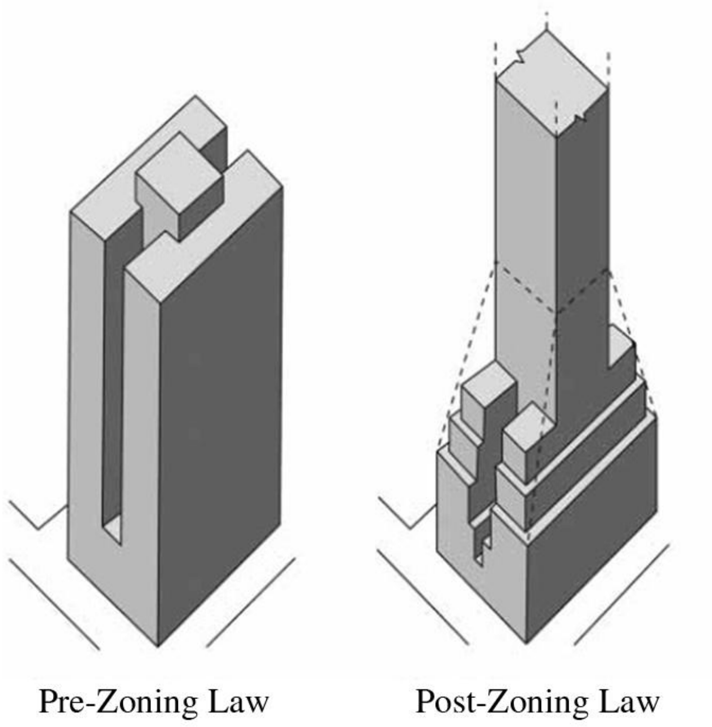


Figure 2.16. Impact of the Zoning Law of 1916
(Source: Oldfield et al., 2009)

The use of glass curtain walls and increased height in buildings made the lateral bracing system towards the centre and merge with the compact service core as a structural member (Trabucco, 2010). As a result, in most of the cases service cores became the primary component of lateral load bearing system of the buildings (Trabucco, 2010). This structurally well-defined service cores also used as emergency areas including fire escapes and fire-protected rooms (Trabucco, 2010). Seagram Building and Lever House (Figure 2.17) are the typical examples of this generation.

2.4.3.4 The 1973 Energy Crisis and Sustainable Approach

With the energy crisis in 1970s, especially architects started to look for new design strategies to come up with more energy efficient buildings (Trabucco, 2010). This sustainable movement has involved using double façades instead of glass curtain wall, applying light windows rather than dark-tinted glazing, optimizing the service cores' energy requirements, etc. (Oldfield *et al.* 2009).

Some professionals, especially architects like Ken Yeang and Norman Foster, have worked on the effect of service core location on the energy consumption of high-rise buildings. High-rise buildings with external service cores are emerged as alternatives of the buildings with typical centrally located service cores due to their energy saving advantages (Trabucco, 2010). For instance, external service cores can provide shading for excessive solar gain or act as buffer zones for heat loss and/or gain (Yeang, 1996). Additionally, there is an opportunity of natural ventilation for toilets, mechanical rooms and other services (Yeang, 1996).

Early examples of this service core configuration can be seen in SOM's Inland Steel and One Bush Buildings, although the external service cores have other purposes than shading (Trabucco, 2010). The Menara Mesinaga (Figure 2.18), the IBM Plaza and the Poly International Plaza (see Figure 2.19) are the other important examples of this generation (Trabucco, 2010).

Figure 2.17. Lever House, 1952, New York
(Source: Google Images)

2.4.3.5 The Future of Service Cores

Oldfield *et al*. (2009) notify that since the organizations are predicting a 1.8ºC to 4ºC increase in temperature by the end of the century, the climate change will be one of the most important challenge to the modern world. Thus, the future examples of the high-rise buildings will go beyond today's sustainability level and provide zero-energy configurations (Ali &Armstrong, 2008). The recent examples of new generation high-rise buildings such as Commerz Bank Tower in Frankfurt and Swiss Re Tower in London improved the effectiveness of the service cores and presented innovative ways of sustainability. Pank, Girardet & Cox (2002: 53) note that "A smarter design is the path to follow to build good quality, low budget skyscrapers and advance service cores could be a good starting point." Architects

Figure 2.18. Menara Mesinaga, 1992, Kuala Lumpur
(Source: Google Images)

have started to look 'outside of the box' in the design process and will discover more complex configurations for the service core design (Yeang, 2006).

2.5 CONSIDERATION OF SERVICE CORE CONFIGURATION REGARDING SUSTAINABILITY

As discussed in the previous sections, after the energy crisis in 1970s a search for energy efficient high-rise buildings have arisen. The designers started to pay greater attention to find some low-energy strategies that can satisfy the required comfort conditions (Yeang & Powell, 2007). As mentioned before, according to the 2007 report of WBCSD, approximately 85 percent of the energy consumed in a building is spent for operation during a 50-year lifespan; while manufacturing,

Figure 2.19. Poly International Plaza, 2006,
Guangzhou (Source: Google Images)

construction, transportation and maintenance share only 15 per cent. Such a high percentage emphasizes the importance of sustainable design measures.

The overall strategy of a sustainable building design is summarized by Gonçalves & Umakoshi (2010) in four steps (Figure 2.20). The first step is about the measures in architectural design to reduce the energy demand. The second step involves the application of energy-efficient technical systems. Steps three and four are about the use of renewable energy supplies such as solar, wind, geothermal energies. Similarly, Yeang & Powell (2007) consider the passive mode strategies as first to handle, because without these measures other applications remain irrelevant or are used to compensate the deficiencies in the architectural design of buildings.

Passive mode is defined as bioclimatic design which involves adopting low-energy strategies related to the locality's climatic and meteorological data (Yeang & Powell, 2007). This climate-response design aims for a year-round comfort by applying completely passive energy techniques (Yeang, 1996). Thus, it seeks for providing required comfort conditions without the application of any electromechanical system. Examples of passive mode design strategies contain; applying appropriate building configuration and orientation to the ambient climate and the seasonal paths of the sun; proper façade design such as an appropriate solid-to-glazed area ratio; natural ventilation of spaces; use of skycourts and atriums; use of renewable materials; and applying appropriate service core location (Yeang & Powell, 2007; Deshmukh, 1992; Beedle *et al*., 2007b).

External service cores can help to optimize the energy performance of a high-rise building significantly (Trabucco, 2008). However, it is a recent approach, and at the same time the traditional central location of service cores has some substantial foundations. The following sections discuss the reasons behind the central location of service cores, contribution of a sustainable service core design to optimization of the energy consumption, and the related studies about this phenomenon.

2.5.1 Reasons for Central Service Cores

Trabucco (2008) states that besides the aim of making them landmark and iconic feature, the most significant objective of high-rise buildings is to get maximum economic efficiency in every detail. To obtain the maximum return from the investment, land owners want to increase the net floor area as much as possible (Trabucco, 2008). Thus, the ratio of net floor area to gross floor area (NFA/GFA) which reflects the floor efficiency becomes the most important factor in the design process. The floor efficiency changes with the function of a building (Park, 2005). For instance, office buildings have generally more elevators than residential buildings corresponding to the same GFA due to the internal traffic. Thus, the

Figure 2.20. The strategy steps for environmental design
(Source: Gonçalves & Umakoshi, 2010)

floor efficiency of office buildings would be lower than the residential buildings. Studies show that the floor efficiency for high-rise office buildings ranges from 70% to 80% depending on height, tenant configurations and other design decisions (Ho, 2007; Kim & Elnimeiri, 2004; Park, 2005; Sev & Özgen 2009; Trabucco, 2008).

As mentioned before, generally, NFA/GFA ratio is dependent on the service core area, and in this context, this ratio is affected by the choice of service core configuration. There are basically two types of configurations of the service core: central/internal and peripheral/external (Trabucco, 2008). Generally, the buildings with peripheral service cores have poorer floor efficiencies. According to Trabucco (2008), such buildings have 3 to 7% less floor efficiency than the buildings with central service cores. This drop is due to the longer corridors required to give way to service area, and vestibules to be connected with the main building (Trabucco, 2008). However, this situation is valid for the high-rise buildings having square or square-like floor plates in which central core can be surrounded by a ring of offices (Trabucco, 2010). In the case of rectangular buildings or buildings built on small parcels, peripheral service core configuration is more advantageous, while central location of service core would end up with offices that are too narrow to be used effectively (Trabucco, 2010).

Another reason behind the central cores is structure-rooted. High-rise buildings can be classified according to their structural systems as interior or exterior structures regarding their primary lateral load-resisting systems (Ali & Moon, 2007). In the case of interior structures, the major lateral load-resisting system is a structural core located within the building (Ali & Moon, 2007). This core usually placed in the center of the building to resist lateral loads and prevent torsional movements (Trabucco, 2008). This structural core is used as a service core at the same time, because the inner and closed nature of it prevents that area to be used as office or living space (Trabucco, 2008). On the other hand, exterior structures are mainly carried by peripheral systems which enable an unconventional exterior service core location.

However, when only these concerns are given priority over the aesthetic and environmental quality of design, buildings will not go beyond the conventional, bland, inarticulate, plain box (Beedle *et al*., 2007a). If a shift in design approach does not occur, deep office plans with air conditioned unhealthy environments do not be challenged (Gonçalves & Umakoshi, 2010). On the other hand, this old-fashioned vision has to be short-term. Because, in the near future the changes in architectural and engineering designs will be mandatory for any building due to maintain the CO_2 emission targets (Gonçalves & Umakoshi, 2010).

2.5.2 Sustainable Service Core Design for Optimizing the Energy Consumption

Trabucco (2008: 942) notes that "the importance of being green as a marketing strategy should be noted, so to enhance the popularity of a brand or a firm, or to obtain building permissions." In fact, the main aim in a bioclimatic high-rise building is to lower the energy consumption (Beedle *et al*., 2007a).

The location of a service core can help to control the shading or retaining the solar radiation (Yeang, 1999). Moreover, the mass of the core can act as a thermal buffer and prevent the excessive heat gain or loss depending on the location of the building (Trabucco, 2008). It is apparent that high-rise buildings are more exposed to sunlight, wind, freeze and other properties of the locality when compared to the lower buildings (Yeang, 1999). Behr (2001) states that because the façade of a high-rise building constitutes 90 to 95% of the total external surface area, the roof area remain unimportant to consider. Thus, the energy consumption of a high-rise building is affected considerably with the façade treatment. In the light of this information, it can be said that an external service core can provide a significant control on optimizing the energy consumption. To sup up, benefits of an external service core configuration can be listed as follows:

1. External service cores can be naturally ventilated. Natural ventilation is important for several reasons. Firstly, free air movement is crucial for human health, because the air quality increases with the removal of odors, carbon monoxide, humidity and any other by-products of the occupants and mechanical devices (Fordham, 2005). Second reason is related with the thermal comfort. The outdoor breeze can be utilized to remove the discomforts arisen from high temperature and uncomfortable indoor

conditions not only in the service area but also through the whole building by structural cooling (Yeang, 1996). Lastly, opportunity of natural ventilation can minimize or eliminate the need of mechanic ventilation units in the service core area or in the building (Yeang, 1996). This optimizes both the initial cost and floor efficiency by reducing the total area for services (Gonçalves & Umakoshi, 2010).

2. Natural sunlight can be provided to the service core area by the openings. This can minimize or totally eliminate the need of artificial lighting in the service core area. Moreover, natural sunlight is good for human psychology and physiology (Yeang, 1996; Beedle *et al*., 2007b).

3. High-rise buildings with external service cores are safer than ones having central service cores. Yıu-Ching (2005: 11) notes that "Due to the building height and number of occupants, early warning and means of escape is also very important for high-rise buildings." The best solution is to control the emergency events by the means of active systems such as fire detection, sprinklers, etc. (Beedle *et al.*, 2007b). However, if these control systems are damaged by the event itself (earthquake, etc.), they may not work. In such a condition, the existence of natural light and ventilation can provide a significant contribution to egress from the escape routes (Yeang, 1996).

4. By providing immediate view from elevator lobbies, external service cores can give opportunity to look out, experience the natural environment and gain awareness of the place. This is inevitably more preferable when compared to artificially-lit and windowless lobbies of central service cores (Yeang, 1996).

5. A better thermal performance can be achieved through an external service core configuration. Sillah (2010) states that windows are the main reason

of a building's heat transfer. To quote Fordham (2005: 20), "large windows lead to large heat losses and heating loads in winter, and they lead to large heat gains and air conditioning loads in summer." High-rise buildings are poor in thermal insulation performance because of their tremendous glass surface area (Yan & Chen, 2005). However, external service cores can act as buffer-zones which prevent direct sunlight and high internal temperatures in hot-humid climates, and heat loss due to winter winds in cold climates (Beedle *et al*., 2007b). Thus, they help to find a balance between the penetration of natural light and minimization of heat transmission (Poon, 2005). When it is considered that approximately 60% ~70% of total the energy used for air conditioning, this protection can lessen the heating and cooling loads considerably (Yan & Chen, 2005).

2.5.3 Related Studies

In the light of the literature discussed in the previous sections, it can be theoretically said that configuration of service cores is a significant factor especially for determining the heating and cooling loads, and external service cores are known as more energy efficient choices. In this section, the related studies about the effect of external service cores in optimizing the energy consumption of high-rise buildings are given. The last study, under the section of 2.5.3.4, also constitutes one of the objectives of this research.

2.5.3.1 Study I: IBM Plaza, Kuala Lumpur, Malaysia

Kuala Lumpur is located at 3.12º N latitude and 101.55º E longitude having a tropical wet climate (Af) according to the Köppen's climate classification (Kottek & Rubel, 2010). The annual average temperature is between a minimum of 22.5ºC and a maximum of 33.2ºC (Figure 2.21). It has 8718 hours in cooling degree corresponding to 99.5 per cent of the year (Climate Consultant version 5.2). Thus, in this region cooling load is the dominant energy consumer for buildings.

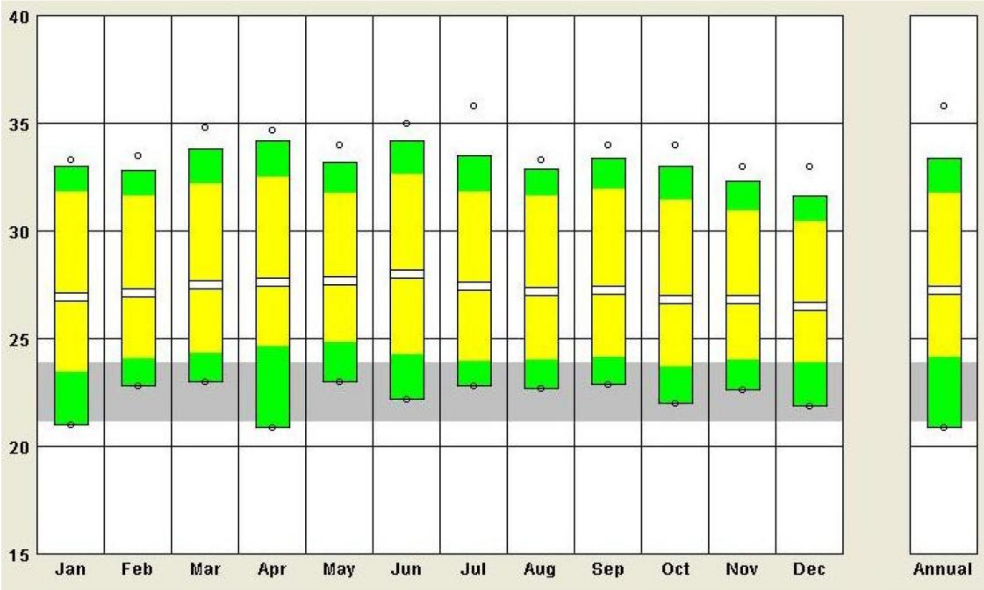
This study is carried out by Jahnkassim and Ip (2006) on IBM Plaza (Figure 2.22) designed by Ken Yeang in Kuala Lumpur. The study examines the Yeang's theory which claims that a high-rise building with split-core configuration in which the service cores are facing east and west like IBM Plaza would provide a reduction in cooling load compared to central service core in tropical climates (Yeang, 2000). The tested service core locations are; generic central core, two end core configurations as east and west, and split core configurations as north-south and east-west (Jahnkassim & Ip, 2006). *IES-VE* (Integrated Environmental Solutions – Virtual Environment) is used for the simulations to examine the effectiveness on cooling loads for different service core configurations (Jahnkassim & Ip, 2006). Results of the study show that the split core - east and west configuration gives the most efficient output by reducing the annual cooling load 8 to 10 per cent (Jahnkassim & Ip, 2006). Figure 2.23 shows the software output about the impact of core location on cooling energy consumption of IBM Plaza.

2.5.3.2 Study II: One Bush Street, San Francisco, USA

San Francisco is located at 37.62º N latitude and 122.4º W longitude having a Mediterranean climate (Csa) with mild winters and warm to hot summers according to the Köppen's climate classification (Kottek & Rubel, 2010). The annual average temperature is between a minimum of 8ºC to a maximum of 25ºC (Figure 2.24). It has 4229 hours in heating degree corresponding to 48.3 per cent of the year (Climate Consultant version 5.2). Thus, in this region heating load is the dominant energy consumer for buildings.

This study is carried out by Trabucco (2008) on One Bush Street Building designed by SOM in San Francisco (Figure 2.25). The study examines the effect

(a)



(b)

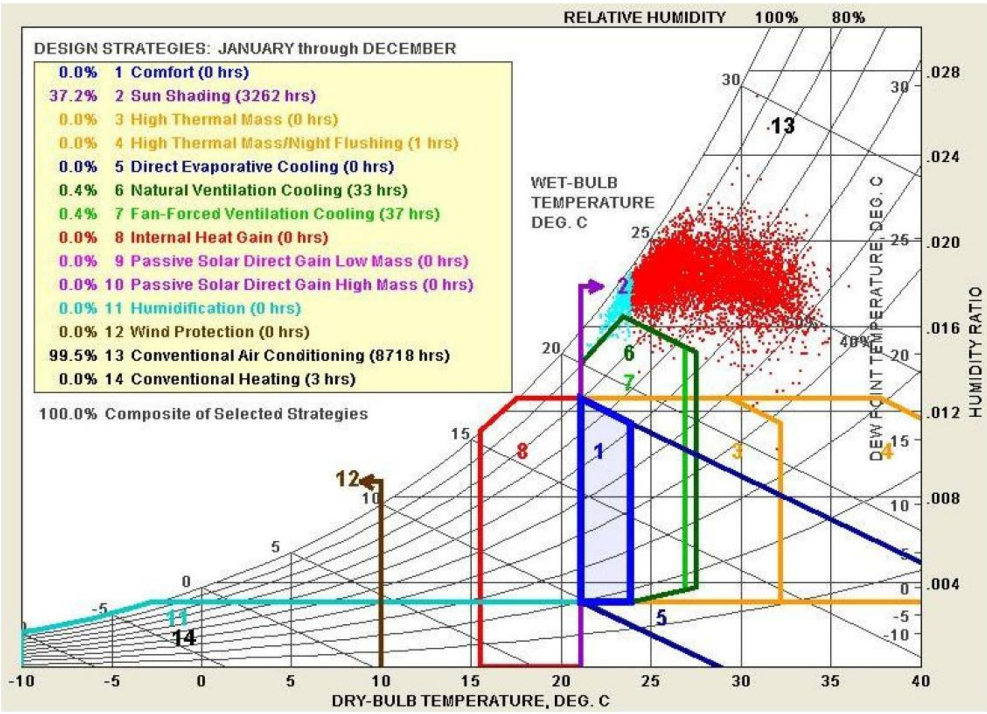


Figure 2.21. Temperature (a) and pshycrometric chart (b) of Kuala Kulmpur (Source: Climate Consultant Software)

(a)

(b)

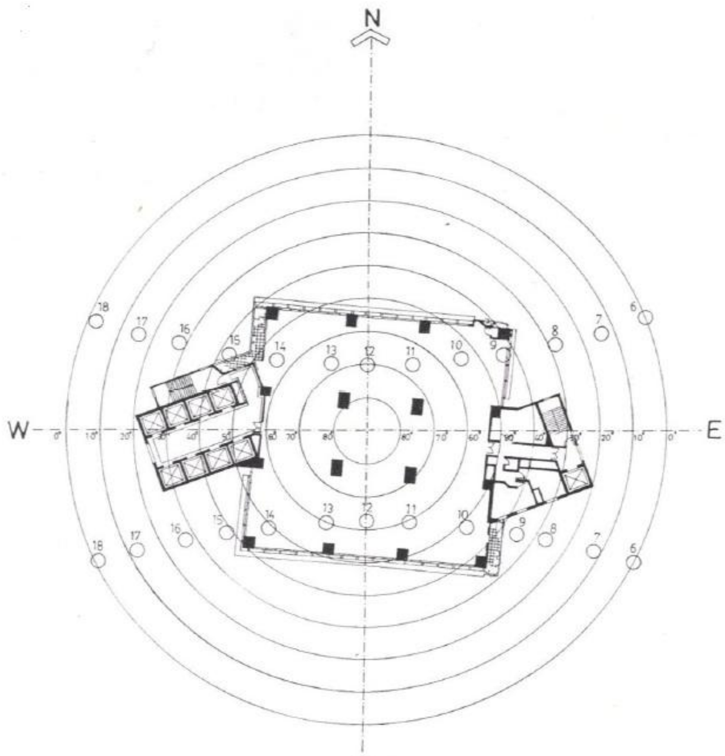


Figure 2.22. Exterior view of IBM Plaza, Kuala Lumpur, Malaysia (a); the floor plan of IBM Plaza (Source: (a) Google Images; (b) Yeang, 1994)

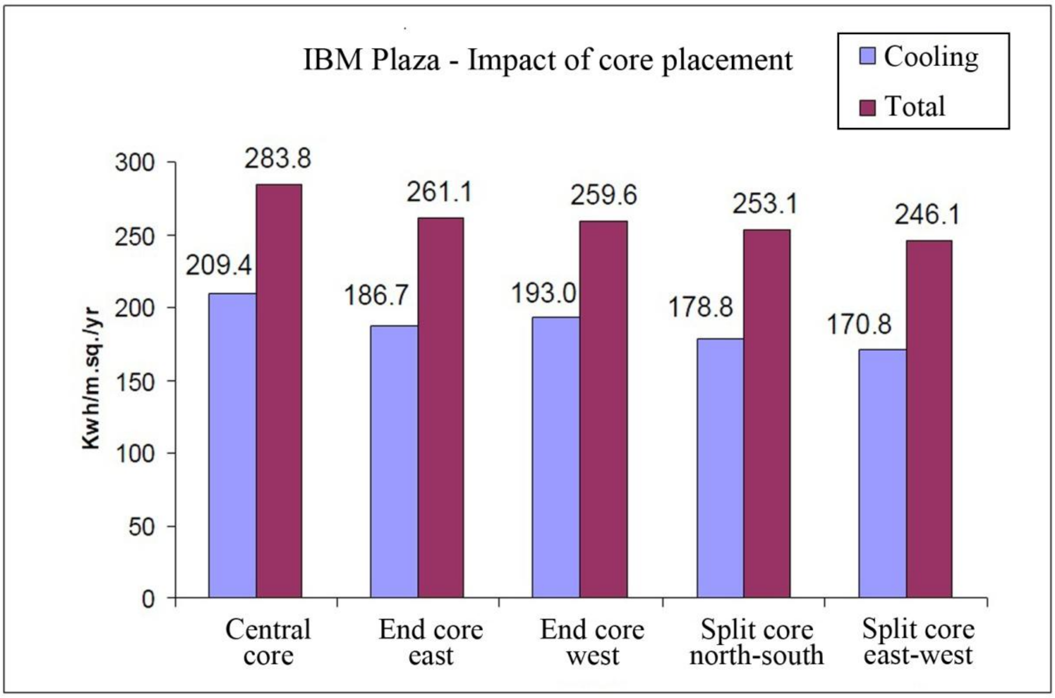
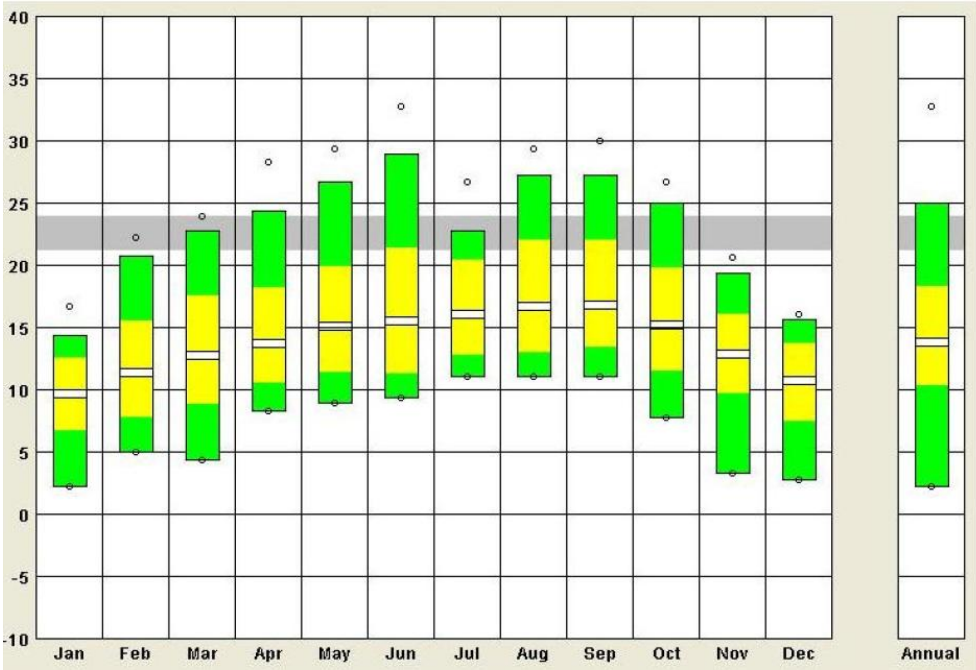


Figure 2.23. Effect of service core location on total and cooling energy consumption of the IBM Plaza (Source: Jahnkassim and Ip, 2006)

of alternative service core configurations on both embodied and operational energy of the building (Trabucco, 2008). However, it is only taken the results for operational energy since the embodied energy is out of the scope of this report. The building has an external service core facing south, and the façade is a typical glass curtain wall. The test is carried out on three models: (1) the actual building, (2) the actual building with central service core but having the same NFA, and (3) the actual building with a naturally ventilated adiabatic service core (Trabucco, 2008). *Energyplus* is used for the simulations within *Design Builder Evaluation Version 1.2.2* (Trabucco, 2008). All the models are simulated for a typical summer day conditions, and the heat which is the by-product of the lightings, cooling system and solar radiation is taken into consideration (Trabucco, 2008). As a result, the study shows that the third model -the actual building with a naturally ventilated adiabatic service core- is the best choice in terms of

(a)



(b)

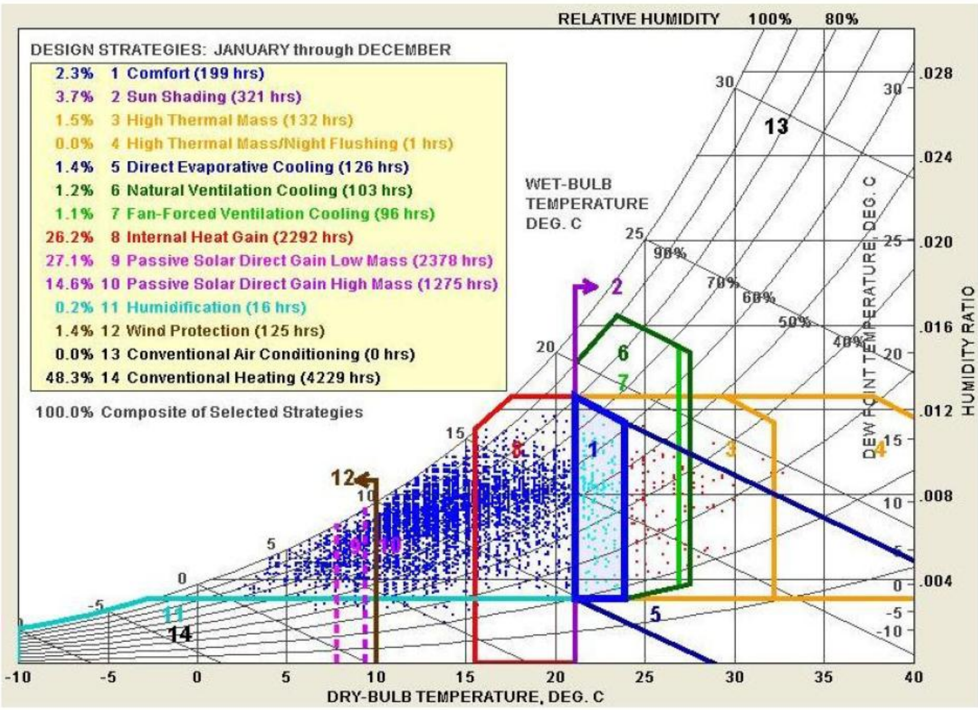


Figure 2.24. Temperature (a) and pshycrometric chart (b) of San Francisco (Source: Climate Consultant Software)

Figure 2.25. External view of One Bush Street, San Francisco
(Source: Google Images)

energy efficiency (Figure 2.26). Reduction in the air conditioned area, buffer-zone effect of the service core, and dissipation of heat gains by natural ventilation are the main reasons of that result (Trabucco, 2008).

2.5.3.3 Study III: The Arts Tower, Sheffield, UK

Sheffield is located at 53.5º N latitude and 1º W longitude having Marine west coast climate (Cfb) with warm summers and cold winters according to the Köppen's climate classification (Kottek & Rubel, 2010). Strong cold winds from the west are dominating the weather and the temperature can easily be drop below 0ºC in winters. It has 7500 hours in heating degree corresponding to 85.6 per cent

Figure 2.26. Results of the simulation for the hottest summer day of the One Bush Street (Source: Trabucco, 2008)

of the year (Chakraborty, 2010). Thus, in this region heating load is the dominant energy consumer for buildings.

This study is carried out by Chakraborty (2010) on The Arts Tower designed by Gollins, Melvin, Ward & Partners in Sheffield (Figure 2.27). The study examines the effect of alternative service core configurations on the heating energy loads of the building for the coldest day, 12th of January of that region (Chakraborty, 2010). The building has a central core, and the façade is a typical glass curtain wall. The test is carried out on seven alternatives of service core configuration: generic with central core, two split core configurations as east-west and north-south, and end core configurations as north, south, east and west (Chakraborty, 2010). *Energyplus* is used for the simulations with *Openstudio*. The simulation is carried out in three stages: (1) passive thermal output variables without any

Figure 2.27. External view of the Art Tower, Sheffield, UK
(Source: Google Images)

heating system in the office zone, (2) heating energy consumption of the office zones where the zones are considered as ideal airtight boxes without any internal gains, and (3) heating energy consumption of the office zone with internal gains in both office and service core zones and air infiltration in office zones only (Chakraborty, 2010). From the results of stage 1, it is found that the end core - north model, followed by the split core - east and west model, has the lowest heat loss. From the results of stage 2 and 3 (Figure 2.28), it is concluded that the split core - east and west model has the lowest heating energy consumption in both of the stages (Chakraborty, 2010).

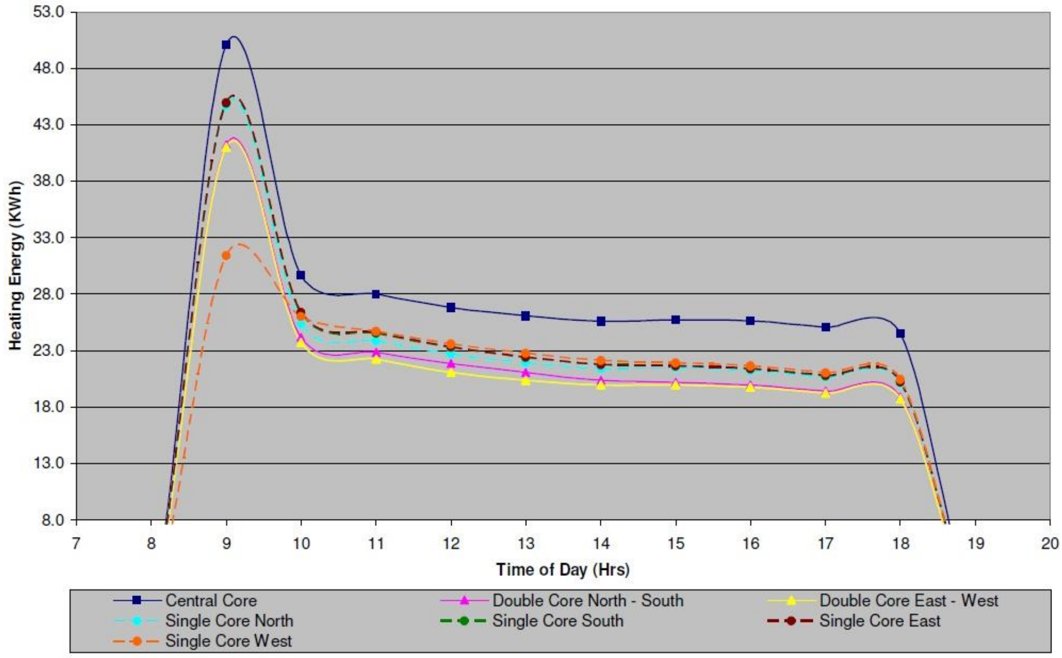
2.5.3.4 Study IV: Alternative designs in Tokyo

Tokyo is situated at 36º N latitude and 140º E longitude having a humid subtropical climate (Cfa) with hot humid summers and generally mild winters with cool spells according to the Köppen's climate classification (Kottek & Rubel, 2010). The annual average temperature is between a minimum of -10ºC to a maximum of 30ºC (Figure 2.29). It has 3140 hours in heating and 381 hours in cooling degree corresponding to 36 and 4 per cent of the year, respectively (Climate Consultant version 5.2). Thus, in this region heating load is the dominant energy consumer for buildings.

This study is carried out by Nihon Sekkei (Yeang, 1999). Sekkei's work is about the correlation among orientation of building mass, service core configuration and cooling load. The study examines sixteen alternative configurations to compare the cooling loads (Figure 2.30). The results show that the split core - east and west configuration provides minimum cooling load.

The study offers a creative look into the issue. However, there are some contradictions. Firstly, it can be observed from the results that orientation has a little effect on cooling loads. In fact, the main difference on the cooling loads are resulted from the change of service core typology. By considering this, it can be

(a)



(b)

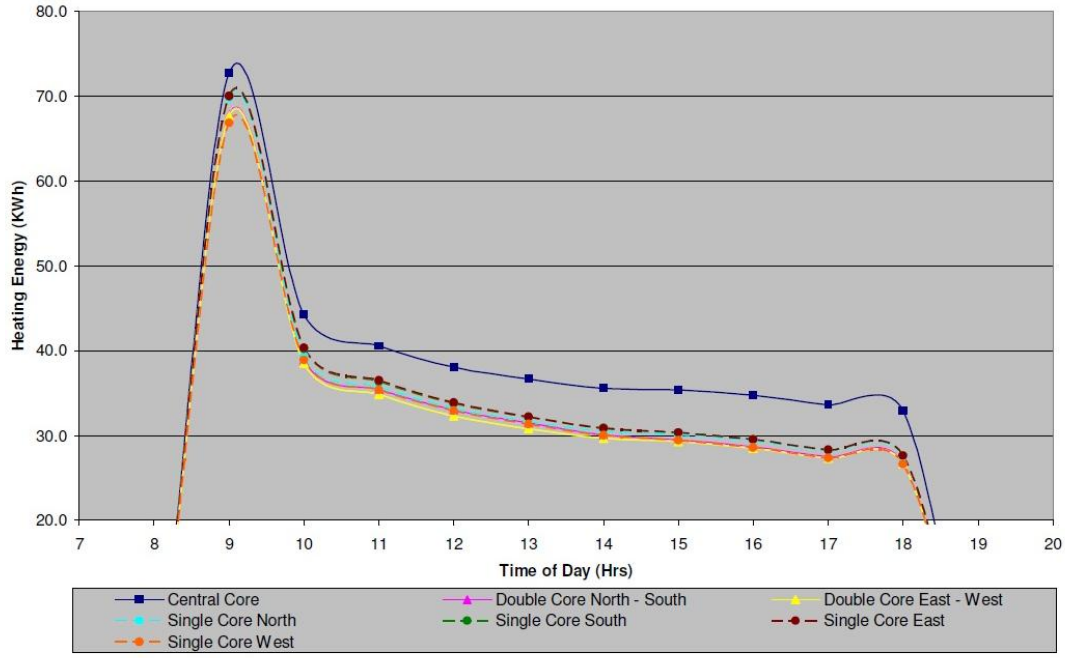


Figure 2.28. Heating energy consumption of office zone without internal gains (a) and with internal gains (b) (Source: Chakraborty, 2010)

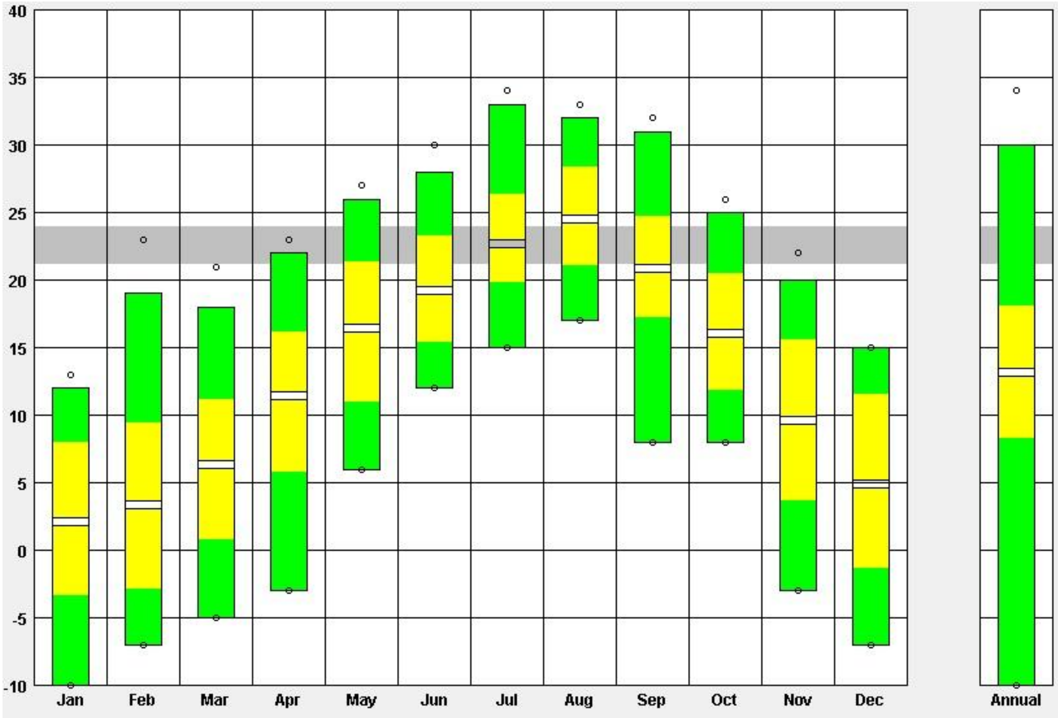


Figure 2.29. Temperature chart of Tokyo (Source: Climate Consultant Software)

said that the main reasons of the reduction in cooling loads are the reduction in glass façade area and buffer zone effect of external service cores rather than orientation of the building mass. In this respect, a greater cooling load difference is expected between the split and end core alternatives which is only 2 per cent in this study. Because, split sore alternatives have two fold opaque surface and buffer zone than the end core alternatives. Secondly, there are irrationalities in the results of some configurations when orientation of the building is considered. For instance, the results of end core - north and end core - south models are 105.4 and 109.7 respectively. However, when the cooling load is in question, a service core located at the south, which is exposed to sunlight all through the day, should contribute to the energy reduction more than the a service core located at the north, which does not get direct sunshine at all. As a consequence, the results should be vice versa. Thirdly, while the heating need is nine fold than the cooling

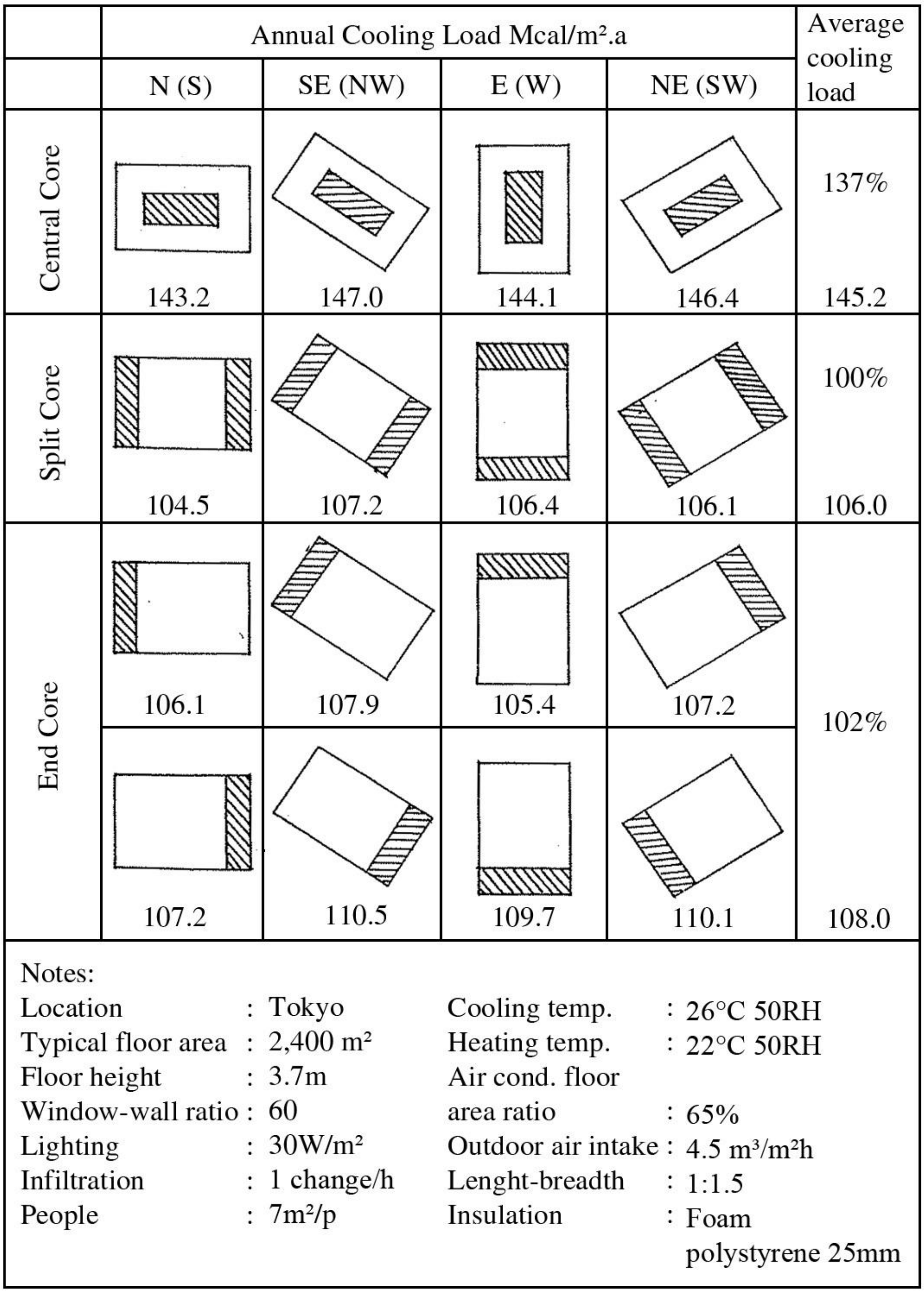


Figure 2.30. Correlation among orientation, service core position and cooling load according to Sekkei (Source: Yeang, 2000)

in Tokyo, the study could be conducted for annual heating load rather than cooling. Additionally, although the gross floor area remains constant, the area of service core - so the net floor area - differs by configuration. To be able to compare the alternatives rationally, all of the design features except the service core configurations should remain constant.

One of the objectives of this thesis to verify the Sekkei's study and enlighten the contradictious parts. Thus, similar configuration alternatives are examined with appropriate gross and net floor areas. Further information is offered in following section, material and method.

2.6 EVALUATION OF THE LITERATURE

It is observed from the literature that at first, to provide more financial profit and comfort in working or living spaces, service cores were located at the darkest and least vulnerable places according to the lot conditions. In later generations, service core got its compact form and sometimes with some additional functions like being a structural component. Moreover, because of some financial and technical reasons, service cores are generally used to be located centrally within the buildings. With the growth of sustainable high-rise buildings, theories about the replacement of service cores towards the periphery of the buildings are propounded. However, there are not enough studies and applications about that approach.

The studies related to the issue are discussed in the previous sections. It is observed that these studies take into consideration either cooling or heating load of the buildings, however there is not a study consider them both. One of the reasons of this condition is that the examined buildings in the studies are generally located in desert or cold geographies where a significant percent of the air conditioning energy is dominated by one of heating and cooling loads. For instance, IBM Plaza which is examined by Jahnkassim and Ip (2006) is situated in

Kuala Lumpur where the buildings in the region require cooling for 99.5 percent of the year. Additionally, Chakraborty's study (2010) on the Arts Tower is conducted for Sheffield where cooling need of the buildings has a share of 85.6 percent in a year. On the other hand, studies of Trabucco (2008) and Sekkei (Yeang, 1999) could consider both heating and cooling loads in order to reach more realistic results. Moreover, Trabucco (2008) and Chakraborty (2010) calculate the loads just of one day of a year which is the coolest or the hottest one according to the climatic conditions of the regions. However, simulations run for an entire year would provide more realistic results.

Another deficiency in the studies is the limited number of service core configuration alternatives. Jahnkassim and Ip (2006), Trabucco (2008) and Chakraborty (2010) examine five, three and seven alternatives, respectively. However, in order to provide a design criterion for designers, more alternatives should be taken into consideration to enable the designers to select proper configurations for their designs. Moreover, as mentioned in the previous sections, external service cores can be designed as passive zones without any heating or cooling applications. This situation is not considered in the studies in which all spaces of the alternative buildings are heated or cooled in the same manner except for the study of Chakraborty (2010). On the other hand, in Chakraborty's study (2010) all of the service core spaces are not air conditioned included the central cores. The best way to control this situation is to simulate buildings for both of the air conditioning scenarios in which the calculations of the external cores are done both for air conditioned and not air conditioned circumstances.

CHAPTER 3

MATERIAL AND METHOD

In this chapter, the details of the material and methodology used in the study are presented under discrete sections. The first section covers descriptions and selection criteria of the subject material. The second section describes the methodology and operational procedure that is used to assess the material.

3.1 MATERIAL

In the study, three hypothetical high-rise building designs are used for various building orientations, which count for a total number of sixteen different alternatives. These building alternatives are designed by considering the Sekkei's study (Yeang, 1999), related standards in literature and Turkish regulations.

Firstly, function of the building is determined. It could be residential, commercial, educational, government, health care, etc. However, when the high-rise building typology is considered, the existing buildings are generally residential or commercial. In this group, majority of the high-rise buildings are commercial which involves shopping mall, office, bank, etc. The function of the buildings used in this study is chosen as office, because in commercial building function, office suits the best for high-rise building typology. Moreover, most of the well-known high-rise buildings are office buildings.

Function of the buildings affects some design decisions. One of them is floor efficiency. As mentioned before, floor efficiency equals to the ratio of net-to-gross floor area (Yeang, 2000), and depends on the function of the building. As discussed in the Literature Review, this ratio varies between 70 per cent and 80 per cent for office function (Ho, 2007; Kim & Elnimeiri, 2004; Park, 2005; Sev & Özgen 2009; and Trabucco, 2008). As a consequence, the floor efficiency is taken as the average value of 75 per cent, for this study. That means, while 75 per cent of the gross floor area is rentable, 25 per cent of it is separated for services of the building.

Another concept that is affected by the function is the required indoor temperature. Although there are different applications in different countries, the required temperature is 19 ºC for office buildings in Turkey. The related 'Turkish Building Regulations for Thermal Insulation', is given in the Appendix A.

The height of the hypothetical buildings is another important criterion that affects some other design concepts. In Turkey, the tallest building is Sapphire Tower with its 261-meter height (CTBUH, 2012). However, the study is proposed to be prudential and aim to enlighten the designers for their coming projects. Moreover, the height race in high-rise buildings and technological developments would lead the way for higher buildings. According to these considerations, the height limit is raised to 300 meters. This value is also high enough to enter the ranking list for top tallest 100 buildings of CTBUH (CTBUH, 2012).

The geometry of the buildings used in this study is settled by considering the Sekkei's study (Yeang, 1999). In order to retrace the Sekkei's findings, the same length-to-width ratio, 1:1.5, is used in the floor plate plan. Although the ratio is kept constant, dimensions of the buildings are different than the Sekkei's study due to provide an appropriate aspect ratio. As mentioned before, aspect ratio or slenderness which equals to height over width ranges between 5:1 and 11:1 for high-rise buildings (Taranath, 2005; Zils & Viise, 2003). However, as stated before, the ratio of 7.5:1 to 8:1 is the most typical and feasible values (Taranath, 2005; Zils & Viise, 2003). For this reason, dimensions of the buildings are considered according to 1:1.5 plan ratio and slenderness between 7.5:1 and 8:1.

While the core location and orientation of the building mass are varying, the overall dimensions of the hypothetical buildings remain constant. The dimensions of the buildings are considered as 32m x 48m. These values fulfill the 1:1.5 plan ratio. Additionally, the aspect ratio is calculated as approximately 7.7:1 which meets the requirements. The calculation is shown below, where A is the aspect ratio, W and D are the plan dimensions, and H is the height of the building.

$$A = \frac{\mathrm{H}}{\sqrt{\mathrm{WD}}} = \frac{300}{\sqrt{32\mathrm{x}48}} = 7.7$$

With these dimensions, the gross floor area is found as 1,536 m². Out of this, the service core area is 384 m² which is the 25 per cent of the GFA. Thus, the NFA of the building is obtained as 1,152 m². The floor to floor height is considered as 4m. The GFA and NFA together with the volume parameters are kept constant throughout the study.

Three alternative service core typologies used in the study which are: (1) central core, (2) end core and (3) split core. In this respect, the Sekkei's work (Yeang, 1999) and the study in this dissertation are in coherence. The service cores of the central core models are located by considering to leave close lease-span values for each side of the buildings throughout the perimeter. Thus, the consequent configuration is shown in Figure 3.1(a). For the split and end core alternatives, the full length of the small edge is used as the common wall with the core area. Therefore, for end core configurations, the width of the core is calculated by dividing the total core area to the common edge length as shown below.

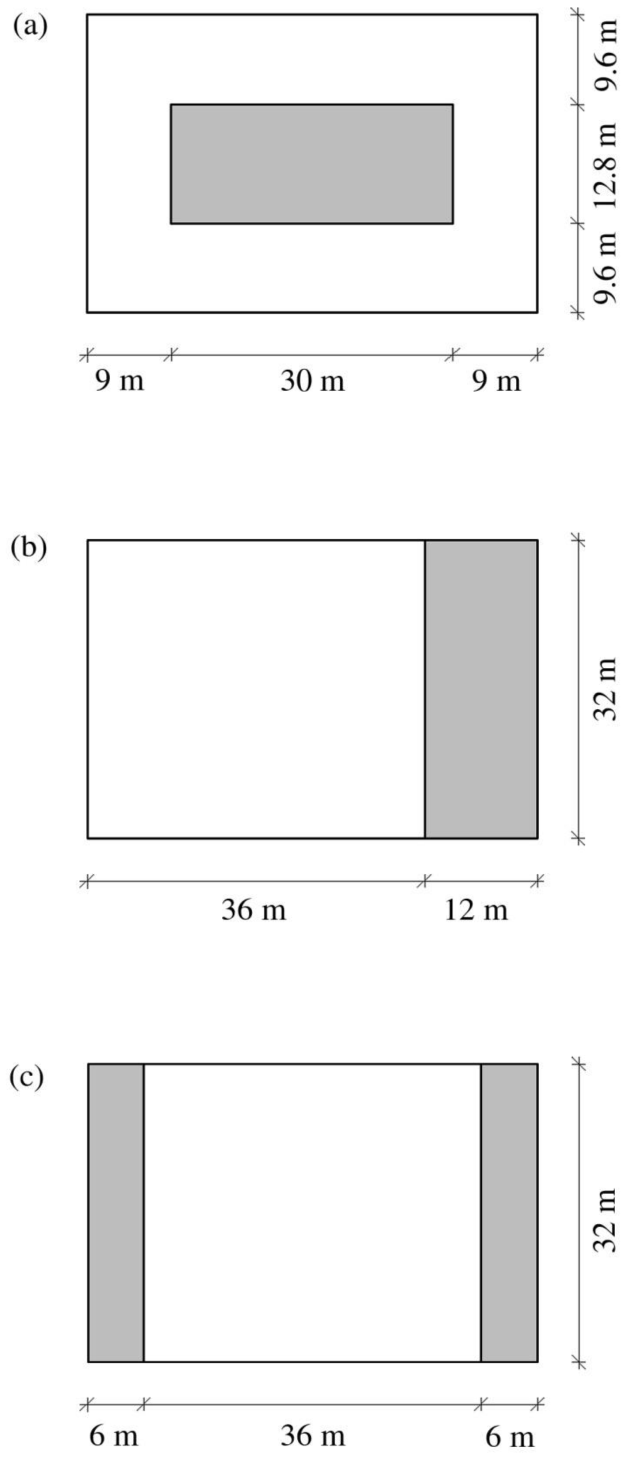


Figure 3.1. Central core (a), end core (b)
and split core (c) configurations used in the study

$$w = \frac{\mathrm{GFA} - \mathrm{NRA}}{\mathrm{D}} = \frac{384}{32} = 12$$

For split core configurations, the 12m width is divided with two to maintain the same service core area. The divided parts are located at the opposite sides of the floor plate plan. The split and end core configurations are shown in Figure 3.1 (b and c) with corresponding dimensions.

The orientation of the building mass is another design criterion. A building can be aligned to infinitely many different directions. However, to conduct the study the alternatives should be reduced to a legitimate number. The main orientations, namely north, south east and west, are not enough to assess the situation, because there is not a linear change between cardinal directions. For instance, if the results of a survey on energy consumption of the building according to the orientations are 40 and 60 units for north and east directions respectively, the result of northeast direction would not be the simple arithmetical average of those values, 50 units, or should not be deducted like that. Thus, the intercardinal directions should also be introduced to reach more valid outcomes. In the study four different orientations are examined, namely: east-west, north-south, southeast-northwest, and northeast-southwest.

There are three different alternatives for service core typologies and four different alternatives for building orientation which end up with sixteen different configurations in total. The alternatives used in the study are shown in Figure 3.2 and can be listed as:

1. Central core - East-to-West
2. Central core - Southeast-to-Northwest
3. Central core - North-to-South
4. Central core - Northeast-to-Southwest
5. End core - East

6. End core - Southeast
7. End core - South
8. End core - Southwest
9. End core - West
10. End core - Northwest
11. End core - North
12. End core - Northeast
13. Split core - East and West
14. Split core - Southeast and Northwest
15. Split core - North and South
16. Split core - Northeast and Southwest

It is important to base the study at a particular geographical location to be able to apply the relevant methodology. In this study, Istanbul is chosen as the representative of Turkey and the cities in similar climatic zones, due to its different climatic conditions and central position in business life which leads the construction of high-rise buildings. The weather data is obtained from the U.S. Department of Energy website in *epw* file extension which is recognized by the program used in the study.

Istanbul is in the humid subtropical climate zone (Cfa) according to the Köppen's climate classification with hot muggy summers and generally mild winters with precipitation coming from mid-latitude cyclones (Kottek & Rubel, 2010). The annual average temperature ranges from a minimum of -8ºC to a maximum of 29ºC (Figure 3.3). As an advantageous coincidence, the climatic zones of Tokyo and Istanbul are the same. Moreover, the annual average temperatures are very close to each other. Therefore, the comparison of the Sekkei's work with this study gains extra validity.

Materials used in the buildings are chosen in a way to fulfill the minimum requirements of 'Turkish Building Regulations for Thermal Insulation, which is

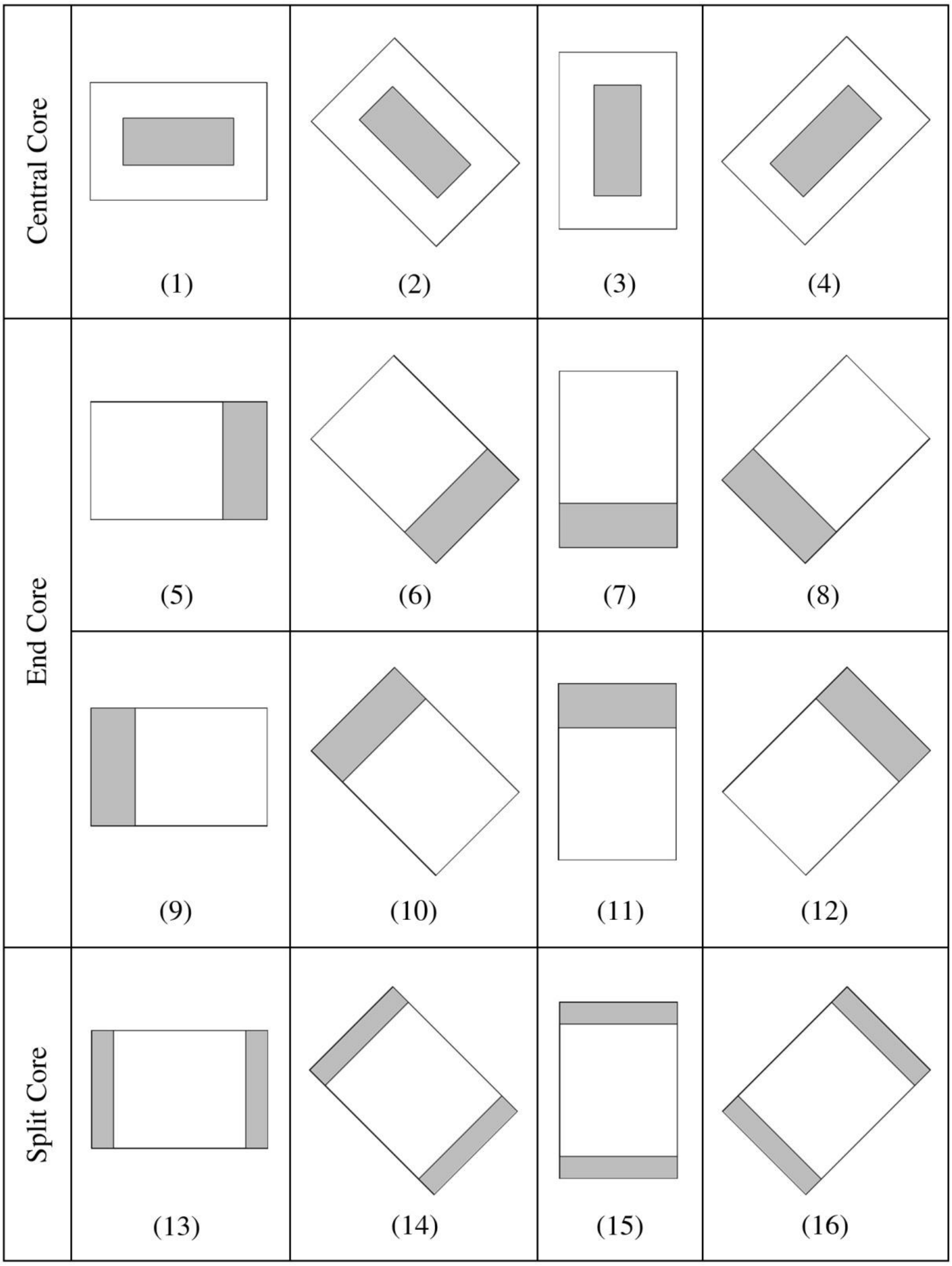


Figure 3.2. Configuration alternatives used in the study

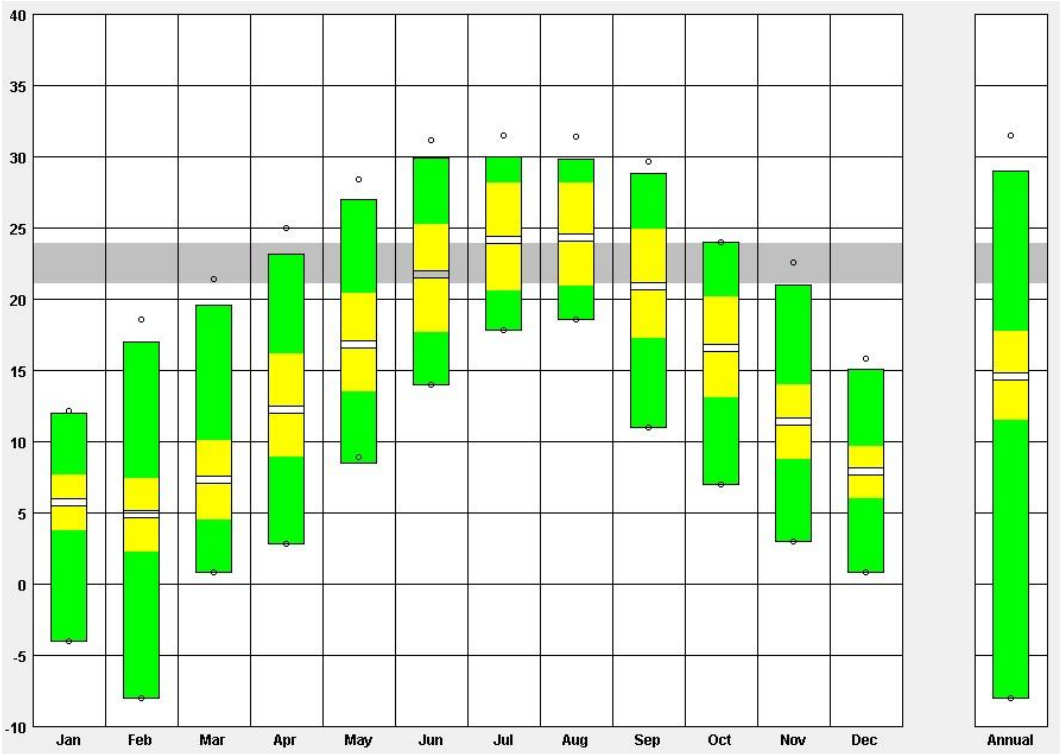


Figure 3.3. Temperature chart of Istanbul
(Source: Climate Consultant Software)

given in the Appendix A. In the regulations, the required U-values, which is the measure of the heat loss or gain due to the temperature differences between indoor and outdoor air, for different construction components are given. The lower the U-value, the better the insulation performance is. In the regulations, Turkey is divided into four zones in terms of their climatic conditions. Therefore, the prescribed U-values are changing with different zones. Although Istanbul, where the hypothetical buildings are located, is in the second zone, the buildings are designed to meet the required values for all the zones as representative prototypes.

The external façades are designed as typical glass curtain walls. The walls of external service cores are solid concrete surfaces, and there are 1.5m x 3m operable windows located at the short edges of the external core alternatives to

Table 3.1. Design details of the buildings

Design Acceptances			
Function	: Office	Service core typologies	: Central core End core Split core
Floor efficiency	: %75		
Indoor temperature	: 19°C		
Height	: 300m	Orientations	: East-West North-South Southeast-Northwest Northeast-Southwest
Plan ratio	: 1:1.5		
Aspect ratio	: 7.7		
Dimensions	: 32m x 48m		
Floor-to-floor height	: 4m	Location	: İstanbul

provide natural ventilation and sunlight. The façade design was kept exactly the same for all sixteen configurations except in areas where external core overlaps on the exterior façade.

3.2 METHOD

The research methodology uses computer simulation tools to assess the alternative models. In this section, reasons behind choice of the thermal simulation program are discussed. Moreover, the simulation process is presented step by step with the relevant input parameters.

3.2.1 Choice of the thermal simulation program

The energy consumptions of the hypothetical buildings can be calculated either on a scaled size real model or by a computer-aided thermal simulation program. The first option would be time consuming, costly and even technically impossible to reach accurate calculations about inside and outside temperatures, heating loads, internal gains, etc. However, thermal simulation programs became advanced and give real-like results. Moreover, they are less time consuming and economical. On the other hand, accuracy of the simulation programs depends on to set the input parameters with appropriate boundary conditions and assumptions. Thus, to understand the system and define the parameters clearly are very important to get valid results.

There are a number of computer programs to perform thermal simulations ranging from simple to very complex. The extent of input parameters defines the complexity of these simulation programs. A good example of these programs is *Energyplus*. The program provides a large number of custom adjustments. Moreover, it offers a wide range of output variations. However, it is a very complex program, and requires in-depth knowledge and experience to be able to set input parameters appropriately. On the other hand, *Ecotect*, another thermal simulation program, is much simpler. Nevertheless, it presents a few options to change any advanced input parameter which leads unrealistic models.

eQUEST is chosen as the thermal simulation tool for this study. It is a user friendly program, and designed to perform comparative analyses of building designs. It allows creating three dimensional models, running simulations, and getting interactive output in a single program. Moreover, it provides a wide range of custom adjustments such as settings of people occupancy, lighting, office equipment, air infiltration, and different operation schedules. These input parameters are combined by 'building creation wizards' of the program which are effective tools to create models with a legitimate level of effort and time. The outputs are given in the form of graphs and data tables. Results are generally based on energy consumption of the models' operation systems; however, output about other issues such as solar radiation transmissions or heat loss/gain through surfaces is not included in the program.

3.2.2 Simulation process

The thermal simulation models of the alternatives are formed stepwise by setting the input parameters. The first step is to define location of the buildings and weather data. Table 3.1 shows geographical details about the location of the buildings. The weather data is introduced to the program as an *epw* file extension, as mentioned before.

After setting the geographical and climatic data, building dimensions are introduced to the program. A typical floor plate of the each alternative is divided into separate zones to be modified uniquely. Basically, there are two types of zones in each floor which are 'office zone' and 'core zone' referring to the net floor and service core areas, respectively. For instance, in the split core configurations there are two 'core zones' and one 'office zone'. Thus, the simulation process makes it possible to assign different thermal conditions to each zone independently.

Input data about the construction of the buildings' surfaces, materials and corresponding U-values has a significant impact on the simulation results. As mentioned before, while a glass curtain wall system is chosen for façade of the office zones, core walls of end and split core configurations are designed as solid concrete surfaces. Table 3.2 shows details of the construction types and their composing materials. Those constructions are settled consciously to meet the

Table 3.2. Geographical details about the location of buildings

Location	Istanbul, Turkey
Latitude	40.97° North
Longitude	28.82° East
Elevation	37m from sea level
Time zone from Greenwich	2

Table 3.3. Constructions of the building surfaces

Name	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
Exterior wall (External core walls)	1 in (25.4 mm) marble	2 in (50.8 mm) polyisocyanurate	8 in (203.2 mm) 140lb heavy-weight concrete	-	-
Interior wall (Central core walls)	1 in (25.4 mm) gypsum board	4 in (101.6 mm) metal wall-frame	1 in (25.4 mm) gypsum board	-	-
Exterior glazing	1/8 in (3.2 mm) clear glass	1/2 in (12.7 mm) argon gas	1/8 in (3.2 mm) clear glass	1/2 in (12.7 mm) argon gas	1/8 in (3.2 mm) clear glass
Exterior floor (Ground floor slab)	1 in (25.4 mm) stone tile	4 in (101.6 mm) 140lb heavy-weight concrete	12 in (304.8 mm) light soil damp	underfloor mat	-
Interior floor	carpet	1.25 in (31.8 mm) 30lb light-weight concrete	3 in (76.2 mm) polyurethane	4 in (101.6 mm) 140lb heavy-weight concrete	-
Roof	1 in (25.4 mm) gravel	3/8 in (19.1 mm) built-up roof	4 in (101.6 mm) polyurethane	6 in (152.4 mm) 140lb heavy-weight concrete	lay-in accoustic tile

Table 3.4. U-values of the exterior surfaces

Surface Name	U-value
Exterior wall (External core walls)	0.36 W/m²K
Exterior glazing	1.9 W/m²K
Exterior floor (Ground floor slab)	0.28 W/m²K
Roof	0.21 W/m²K

Table 3.5. The air infiltration rates (* indicates reference to CIBSE, 1986, ** indicates reference to ASHRAE 90.1)

Zone Name	Schedule	Air changes per hour
Office zone	Always on	1 *
Core zone (exterior walls of exterior core configurations)	Always on	0.5 **

required U-values dictated by the Turkish regulations. The obtained U-values are listed in Table 3.3, and Table 3.4 shows air infiltration rates of the surfaces.

Space heating not only depends on the heating system or solar gain, but the heat radiating from people, lights, and machines as well. Thus, a people occupancy schedule, a lighting system, and office equipments such as computers, fax machines and printers are assigned to the simulation program as internal gains. The building configuration affects the amount of heat obtained from those sources. In the case of this study, the variation in service core configuration accounts for the change in internal gains. For instance, in central core configurations, all the heat generated in the service core by people, lights, and other equipment permeates to the office zone through interior walls. However, in the case of external core configurations, namely split and end core alternatives, only some part of this heat affects the office zone, while most of it dissipates through the external walls to the environment.

External service cores can be designed in different ways than central service cores in terms of the HVAC systems. First of all, external service cores are advantageous due to the opportunity of natural ventilation which can lessen or eliminate the need for mechanical ventilation. Secondly, external service cores can be treated as passive zones without any air conditioning, because the internal temperature of these spaces does not affect the office areas remarkably as discussed previously. Thus, the heating and cooling system could be minimized or totally eliminated in such service core configurations. On the other hand, central service cores are generally treated like office spaces in terms of thermal conditions, because internal temperature of central service cores affects the office zones significantly. Thus, to maintain the thermal comfort, central service cores are heated or cooled in the same way with office spaces. According to these considerations, the simulations are realized for two different scenarios:

1. All zones of the configuration alternatives are treated in the same way in terms of the HVAC system. The same heating, cooling and ventilation schedules are applied to both of office and core zones in the buildings.

2. The HVAC system differs with the zones. While central core configurations are simulated in the same way with the previous scenario, service core spaces of split and end core configurations are not air conditioned, and considered as passive zones.

The simulations are run for an entire year. However, the operation systems introduced to the program start to operate according to the occupancy schedule of the buildings. Table 3.5 shows the building occupancy schedules and the operation periods of the systems introduced to the buildings. Table 3.6 describes the people occupancy schedule with occupancy level in the office and core zones. Table 3.7 and Table 3.8 give details about input parameters of the lighting system and the equipment which is assigned only to the office zones.

The heating system assigned to the simulation program operates according to the heating system schedule. The schedule pattern is set to a constant thermostat set-point. The set-point is determined consciously to meet the requirements of Turkish Building Regulations for Thermal Insulation given in the Appendix A. The regulations dictate 19ºC of indoor temperature for office buildings. Thus, the set- point temperature is fixed to 19ºC in the program. Within the running periods, the heating system begins to operate when the indoor temperature drops under the thermostat set-point temperature. Those details are given in Table 3.9.

The cooling system of the buildings works in the same way. When the indoor temperature rises up to 19ºC, the system begins to work within the operation schedules. Table 3.10 shows the related input parameters. As mentioned before, both the cooling and the heating systems are not assigned to core zones of split and end core alternatives in the second scenario simulations.

Through the simulation process, some assumptions are made which affect the simulation results. Thus, it is important to define them to maintain validity of the study. Moreover, all the information about the simulation process could be significant for the possible future works that are based on this study.

Internal gain does not only ensue from the people, lighting system and equipments in buildings. The heat radiating from elevators, pumps, water risers, gas lines, or other machinery of the HVAC system also has a share on the thermal condition of buildings. The heat radiating from those components would mainly be spread from mechanical rooms which are generally located at the under-ground floors. In the case of high-rise buildings, mechanical rooms can be placed at mid-floors

Table 3.6. Operation schedules of the buildings

	Building operation schedule		Lighting system schedule		Office equipment schedule		Heating system schedule		Cooling system schedule	
Operation	Entire year		Entire year		Entire year		Thermostat setpoint		Thermostat setpoint	
	on at	off at	on at	off at	on at	off at	on at	off at	on at	off at
Monday	8 am	6 pm	8 am	6 pm	8 am	6 pm	7 am	7 pm	7 am	7 pm
Tuesday	8 am	6 pm	8 am	6 pm	8 am	6 pm	7 am	7 pm	7 am	7 pm
Wednesday	8 am	6 pm	8 am	6 pm	8 am	6 pm	7 am	7 pm	7 am	7 pm
Thursday	8 am	6 pm	8 am	6 pm	8 am	6 pm	7 am	7 pm	7 am	7 pm
Friday	8 am	6 pm	8 am	6 pm	8 am	6 pm	7 am	7 pm	7 am	7 pm
Saturday	-	-	-	-	-	-	-	-	-	-
Sunday	-	-	-	-	-	-	-	-	-	-

Table 3.7. Input parameters of the people occupancy schedule
(*indicates *eQUEST* default value for office function)

	Office people	Service core people
Schedule	Building occupancy schedule	Building occupancy schedule
Zone	Office zone	Core zone
Calculation method	1 person per 10 m²*	1 person per 20 m²
Number of people	116	20

Table 3.8. Input parameters of the lighting system schedule
(*indicates reference to ASHRAE 90.1)

	Office lights	Service core lights - scenario I	Exterior service core lights - scenario II
Schedule	Lighting system schedule	Lighting system schedule	Lighting system schedule
Zone	Office zone	Core zone	Core zone
Value	12 Watt/m²*	12 Watt/m²*	0

Table 3.9. Input parameters of the office equipment schedule
(*indicates *eQUEST* default value for office function)

Field	Office equipment
Schedule	Office equipment schedule
Zone	Office zone
Value	15 Watt/m²*

and/or top of the buildings. However, such kind of rooms are not designed for this study. Moreover, the heat coming from friction of the elevator system and risers is neglected. On the other hand, the abovementioned heat sources could be significant and need to be determined in further studies.

During the simulation, most of the input parameters are determined according to building dimensions and related standards. However, some parameters are filled by *eQUEST* default values as indicated in the tables. Although these values are generally determined for office buildings, the actual values should be introduced to the program if more accurate results are needed for a specific project.

Table 3.10. Input parameters of the heating system

Heating system			
Schedule	Heating system schedule		
Air-side system		Water-side system	
Heating source	Hot water coils	Boiler type	Electric steam boiler
System type	Standard VAV with HW reheat	Boiler fuel	Electricity
Returned air path	Ducted	Boiler output	> 2500 kBtuh
Thermostat setpoint	19°C	Boiler efficiency	98 %
Supply/return fans type	Variable speed drive	Pump configuration	Single system pump
Fan efficiency	High	HW loop flow	Constant
		Motor efficiency	High

Table 3.11. Input parameters of the cooling system

Cooling system			
Schedule		Cooling system schedule	
Air-side system		Water-side system	
Cooling source	Chilled water coils	Chiller type	Electric centrifugal hermetic
System type	Standard VAV with HW reheat	Condenser type	Electricity
Returned air path	Ducted	Boiler output	> 300 tons
Thermostat setpoint	19°C	Boiler efficiency	0.676 kW/ton
Supply/return fans type	Variable speed drive	Pump configuration	Single system pump
Fan efficiency	High	HW loop flow	Constant
		Motor efficiency	High

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents results and discussion of the thermal simulation program. As mentioned in the previous chapter, sixteen alternative configurations and two air conditioning scenarios are used in the study. The annual energy consumptions of the alternatives are simulated, and results are given in graphs and tabulated data. Besides the discussion of results, a comparative summary is proposed at the end of each scenario as a design guide. Scenarios are defined as follows:

1. All the spaces of the hypothetical buildings are heated, cooled and ventilated in same way. There is no difference between the office and core zones.

2. While the central core alternatives remain the same with the previous scenario, the HVAC system is only applied to the office zones of the split and end core alternatives in which the service core areas are considered as passive zones without any air conditioning.

4.1 SCENARIO I

In the first scenario, the buildings are treated as a single zone. Thus, the service core spaces are air conditioned in the same manner with the office spaces. Results of the simulations are based on annual energy consumptions of the building alternatives. These energy consumptions ensue from the lighting systems, office equipments, ventilation fans, heat rejection systems, and heating and cooling systems of the buildings. However, differences in the energy consumptions of the alternative configurations mainly depend on the heating and cooling energy consumptions. Since, while the NFA and number of people assigned to the alternative simulation models remain constant, the energy consumption of the lighting system, office equipments, and ventilation would be similar for all of the alternatives.

Figure 4.1 shows the monthly energy consumptions of the sixteen alternatives. As can be seen from the graph, the alternatives belong to each service core typology - namely central, end and split core - present quite close results within themselves. The highest energy consumption results are obtained from the central core models owing to the presence of glazing on four sides. Because of the low U-values of glazing constructions, they cause a significant amount of heat loss in winter and heat gain in summer which increases the heating and cooling loads. Within the central core alternatives, the central core - northeast to southwest model has the highest energy consumption.

End core models have average values. However, the end core - west model shows the lowest energy consumption within its group. The split core models have the best results in terms of energy efficiency. However, it is interesting that in the months between May and September, which the outside temperature is possibly higher than the required indoor temperature, the energy consumptions of the split core models are slightly higher than or very close to the end core models. The most energy efficient alternative is the split core - east and west model which provides shield for low-angled sunlight coming from east and west in summer, and maximizes solar gain from glazed south façade in winter. The tabulated data of the graph is given in Table 4.1.

Figure 4.2 shows the annual heating and cooling energy consumptions of the alternatives. It can be observed that, the energy consumed by the heating systems

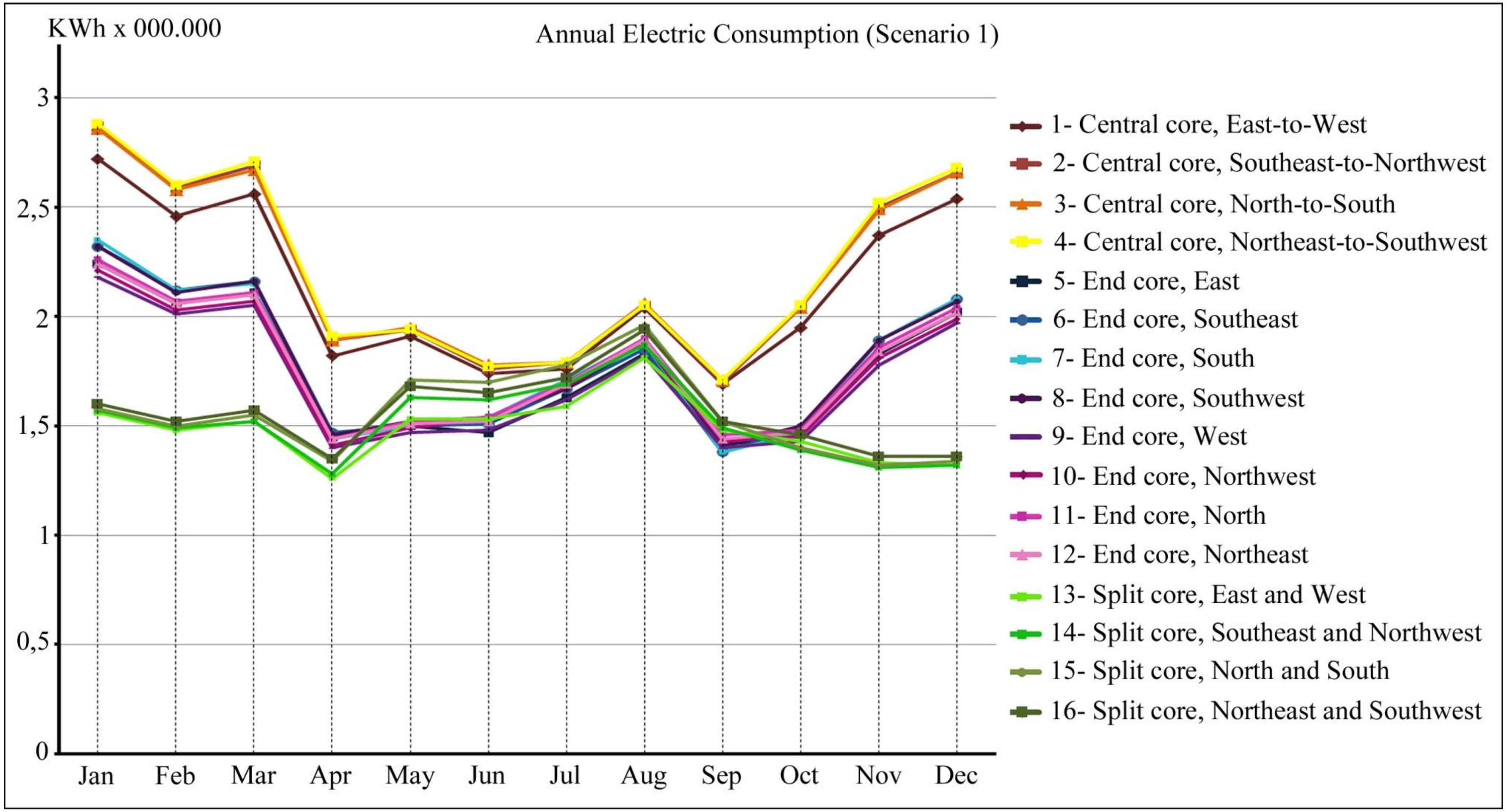
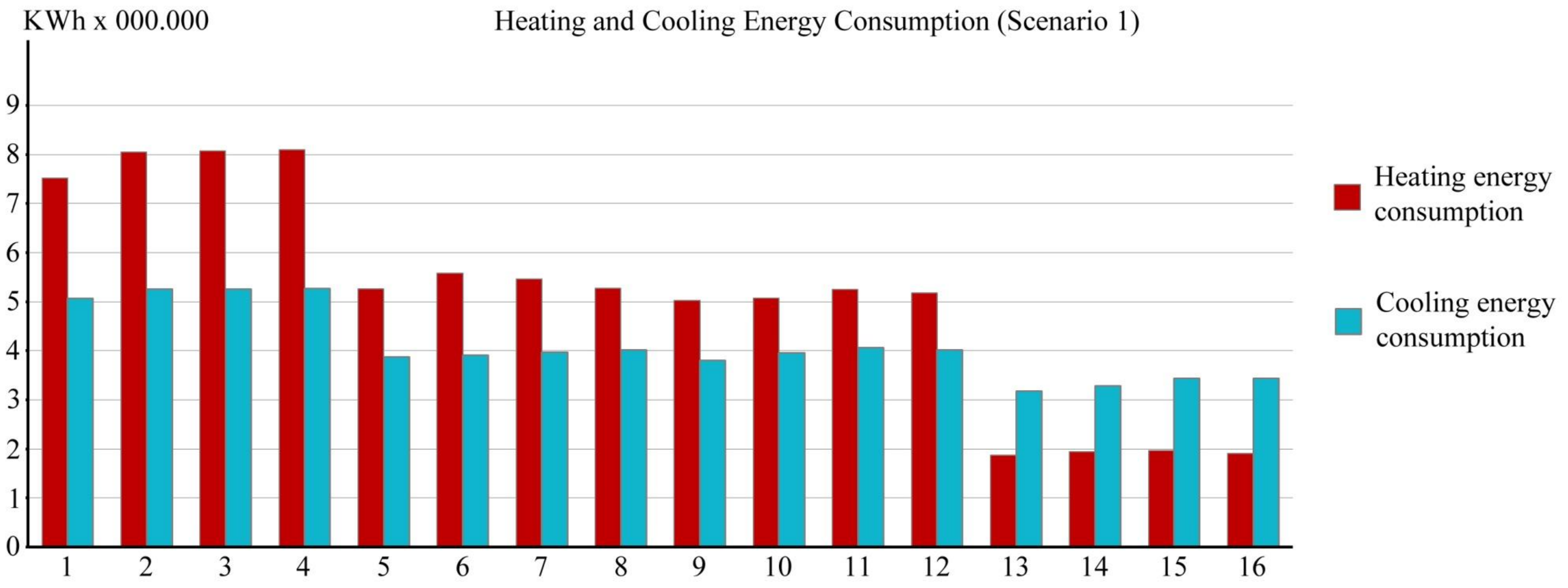


Figure 4.1. Results of the thermal simulation showing total energy consumption of the sixteen alternatives for scenario 1

Table 4.2. Monthly and total energy consumptions of the sixteen alternatives (in kWh x 000,000) for scenario 1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1- Central core, East-to-West	2,72	2,46	2,56	1,82	1,91	1,74	1,76	2,04	1,69	1,95	2,37	2,54	25,55
2- Central core, Southeast-to-Northwest	2,87	2,59	2,69	1,89	1,94	1,76	1,79	2,05	1,70	2,04	2,50	2,66	26,48
3- Central core, North-to-South	2,86	2,58	2,67	1,89	1,95	1,78	1,79	2,06	1,71	2,04	2,49	2,66	26,49
4- Central core, Northeast-to-Southwest	2,88	2,60	2,71	1,91	1,94	1,77	1,79	2,05	1,71	2,05	2,52	2,68	26,60
5- End core, East	2,24	2,06	2,11	1,45	1,50	1,47	1,63	1,83	1,41	1,46	1,83	2,02	21,01
6- End core, Southeast	2,32	2,12	2,16	1,47	1,50	1,51	1,67	1,85	1,38	1,49	1,89	2,08	21,44
7- End core, South	2,35	2,12	2,15	1,44	1,50	1,54	1,71	1,89	1,38	1,47	1,89	2,08	21,54
8- End core, Southwest	2,32	2,11	2,16	1,46	1,52	1,54	1,67	1,88	1,41	1,50	1,89	2,07	21,52
9- End core, West	2,18	2,01	2,05	1,40	1,47	1,48	1,62	1,82	1,40	1,43	1,78	1,97	20,62
10- End core, Northwest	2,21	2,03	2,07	1,41	1,49	1,53	1,68	1,88	1,43	1,45	1,81	1,99	20,96
11- End core, North	2,26	2,07	2,11	1,44	1,52	1,54	1,70	1,90	1,46	1,48	1,86	2,04	21,37
12- End core, Northeast	2,24	2,06	2,10	1,44	1,51	1,52	1,69	1,89	1,44	1,47	1,84	2,02	21,24
13- Split core, East and West	1,56	1,48	1,52	1,26	1,53	1,53	1,59	1,81	1,48	1,43	1,33	1,32	17,84
14- Split core, Southeast and Northwest	1,57	1,49	1,52	1,28	1,63	1,62	1,69	1,87	1,49	1,39	1,31	1,32	18,19
15- Split core, North and South	1,58	1,50	1,55	1,34	1,71	1,70	1,78	1,96	1,52	1,40	1,32	1,34	18,70
16- Split core, Northeast and Southwest	1,60	1,52	1,57	1,35	1,68	1,65	1,72	1,94	1,52	1,46	1,36	1,36	18,74



1- Central core, East-to-West
2- Central core, Southeast-to-Northwest
3- Central core, North-to-South
4- Central core, Northeast-to-Southwest
5- End core, East
6- End core, Southeast
7- End core, South
8- End core, Southwest
9- End core, West
10- End core, Northwest
11- End core, North
12- End core, Northeast
13- Split core, East and West
14- Split core, Southeast and Northwest
15- Split core, North and South
16- Split core, Northeast and Southwest

Figure 4.2. Results of the thermal simulation showing annual heating and cooling energy consumption of the alternatives for scenario 1

is more affected with the change of service core configuration than the energy consumed by the cooling systems. Interestingly, while the climatic conditions of Istanbul necessitate heating more than cooling during the year, the split core models show the opposite results in which the cooling energy consumptions are higher than the heating energy consumptions. This situation explains the similar energy consumptions of the split and end core alternatives between the months of May and September mentioned above.

A comparative summary of the first scenario is presented in Figure 4.3. The central core - northeast to southwest model is rated as 100 per cent due to being the most energy consuming alternative. The other configurations are rated with respect to this model. The results show that the main difference in the energy consumptions is resulted from the service core type rather than the location of it or the orientation of the building. While the highest difference in the energy consumption due to the orientation is 3.5 per cent between the end core - south and the end core - west models, it is observed that significant savings can be achieved up to 33 per cent in the total energy consumption by changing the service core type.

4.2 SCENARIO II

In the second scenario, the office and core zones are separated in terms of the indoor thermal conditions. While the office zones are air conditioned in a same way with the previous scenario, the external core zones consisting the end and split core configurations, are treated as passive zones without any HVAC application.

External service cores are advantageous due to the opportunity of natural ventilation. Moreover, service core areas include unoccupied spaces like mechanical rooms, safe rooms, and installation shafts where there is no need for heating, cooling or ventilation. Additionally, the occupied areas like elevator

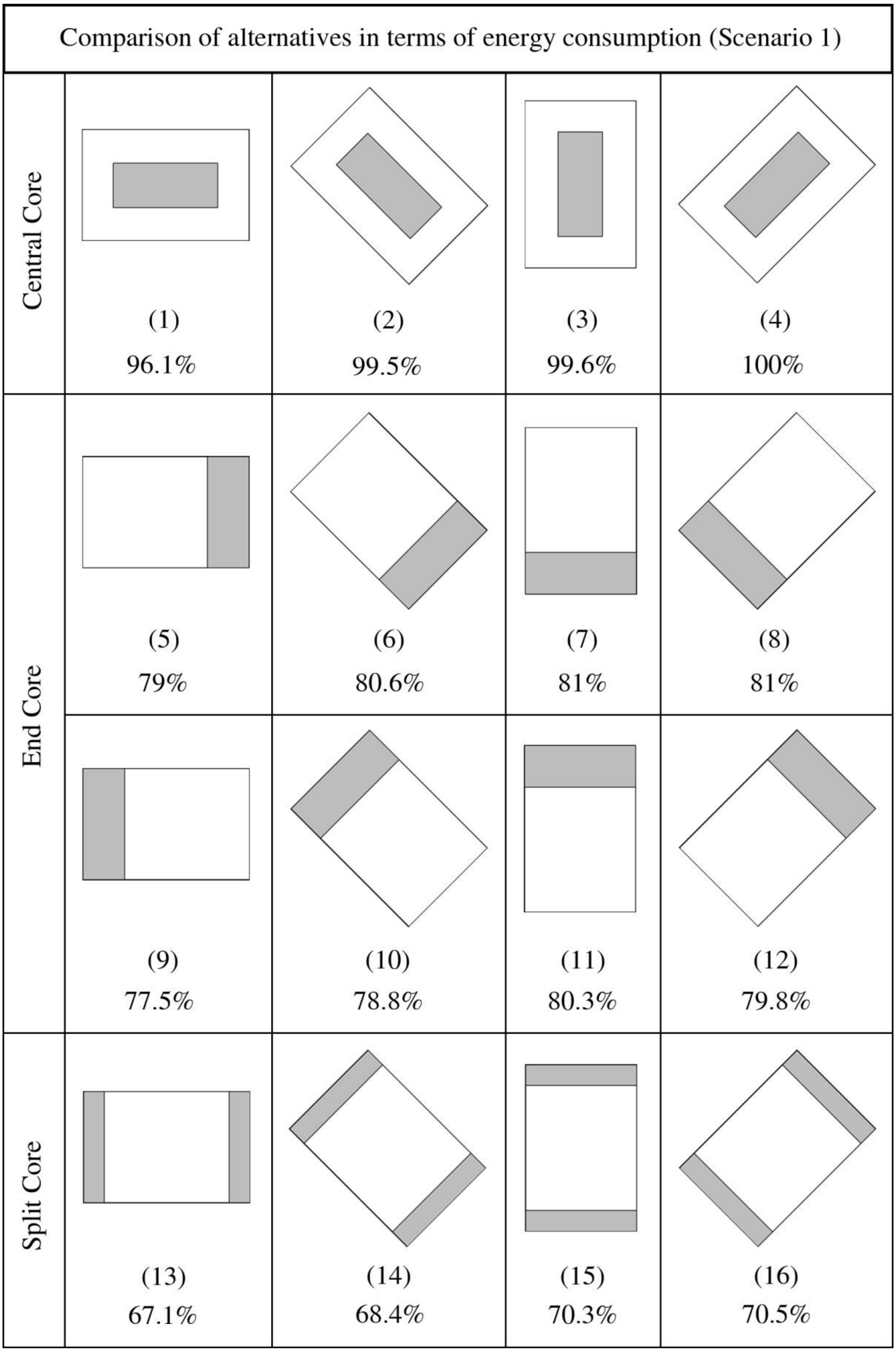


Figure 4.3. Comparative simulation results of the sixteen alternatives for the first scenario

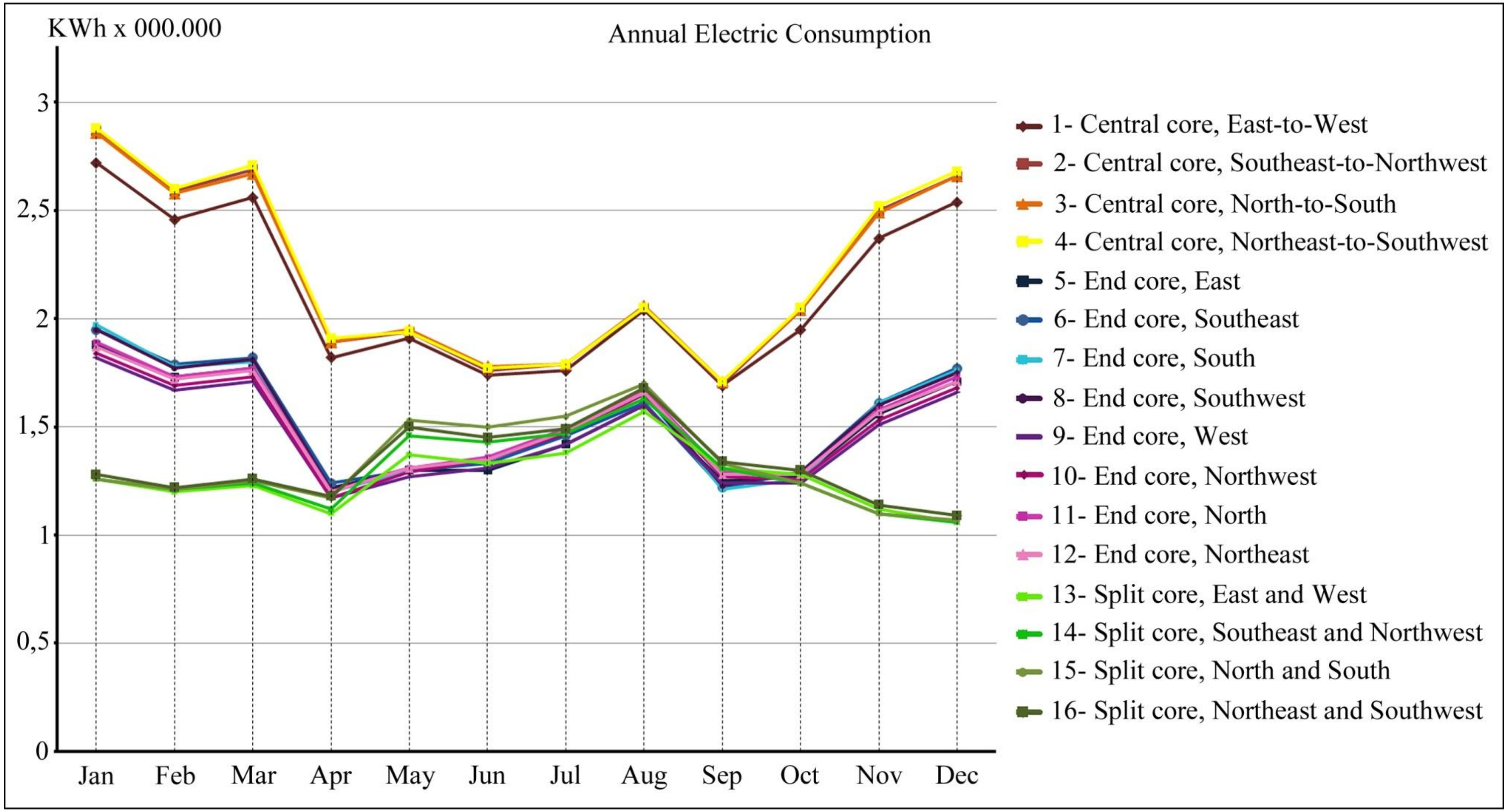


Figure 4.4.. Results of the thermal simulation showing total energy consumption of the sixteen alternatives for scenario 2

Table 4.2. Monthly and total energy consumptions of the sixteen alternatives (in kWh x 000,000) for scenario 2

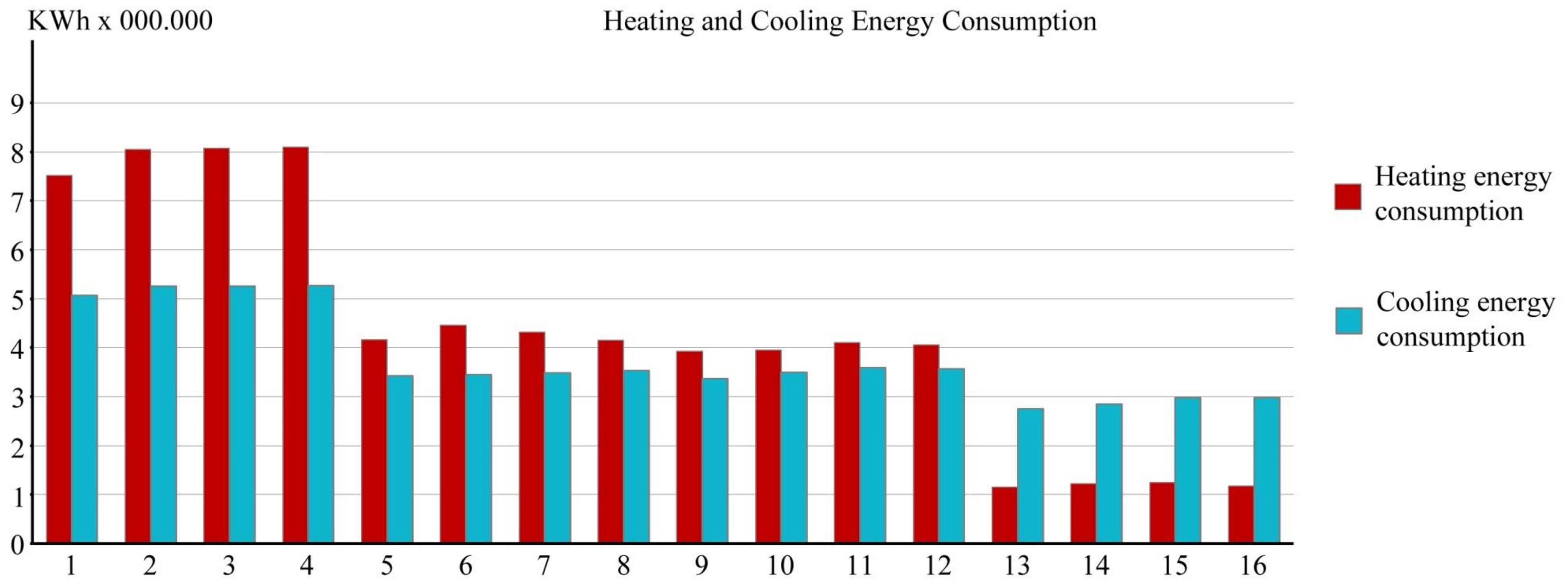
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1- Central core, East-to-West	2,72	2,46	2,56	1,82	1,91	1,74	1,76	2,04	1,69	1,95	2,37	2,54	25,55
2- Central core, Southeast-to-Northwest	2,87	2,59	2,69	1,89	1,94	1,76	1,79	2,05	1,70	2,04	2,50	2,66	26,48
3- Central core, North-to-South	2,86	2,58	2,67	1,89	1,95	1,78	1,79	2,06	1,71	2,04	2,49	2,66	26,49
4- Central core, Northeast-to-Southwest	2,88	2,60	2,71	1,91	1,94	1,77	1,79	2,05	1,71	2,05	2,52	2,68	26,60
5- End core, East	1,88	1,73	1,77	1,22	1,30	1,30	1,42	1,60	1,25	1,27	1,56	1,71	18,01
6- End core, Southeast	1,95	1,79	1,82	1,24	1,30	1,33	1,46	1,61	1,22	1,29	1,61	1,77	18,38
7- End core, South	1,97	1,78	1,80	1,20	1,30	1,35	1,49	1,65	1,21	1,26	1,61	1,76	18,39
8- End core, Southwest	1,95	1,77	1,81	1,21	1,31	1,35	1,47	1,65	1,23	1,29	1,60	1,75	18,38
9- End core, West	1,82	1,67	1,71	1,17	1,27	1,31	1,42	1,60	1,24	1,24	1,51	1,66	17,63
10- End core, Northwest	1,84	1,69	1,73	1,17	1,29	1,35	1,47	1,65	1,27	1,26	1,53	1,68	17,94
11- End core, North	1,89	1,73	1,77	1,20	1,31	1,36	1,49	1,67	1,29	1,28	1,58	1,73	18,30
12- End core, Northeast	1,87	1,72	1,76	1,20	1,31	1,35	1,48	1,66	1,28	1,28	1,57	1,71	18,18
13- Split core, East and West	1,26	1,20	1,23	1,10	1,37	1,33	1,38	1,57	1,31	1,28	1,12	1,06	15,21
14- Split core, Southeast and Northwest	1,26	1,21	1,24	1,12	1,46	1,43	1,47	1,63	1,31	1,24	1,10	1,06	15,51
15- Split core, North and South	1,26	1,21	1,25	1,17	1,53	1,50	1,55	1,70	1,33	1,24	1,10	1,07	15,91
16- Split core, Northeast and Southwest	1,28	1,22	1,26	1,18	1,50	1,45	1,49	1,68	1,34	1,30	1,14	1,09	15,93

lobbies and toilets do not require the same indoor temperature with the office spaces, and at the same time the internal temperature of those areas does not affect the office spaces remarkably as discussed previously. Thus, the air conditioning need for service core is less or can be totally eliminated depending on the climatic conditions of the building location. As a consequence, the simulation results of the second scenario are worth considering.

Figure 4.4 shows the monthly energy consumptions of the sixteen alternatives for the second scenario. The trends in the graph are similar with the previous scenario. However, difference between the energy consumption values of the service core types are more than the previous (Table 4.2). The main reason of this change is the reduced amount of HVAC energy consumption applied to the peripheral core zones in the previous scenario. Similar with the previous scenario, while the central core - northeast to southwest model has the highest energy consumption, split core - east and west model is resulted as the most energy efficient alternative.

Figure 4.5 shows the annual heating and cooling energy consumptions of the alternatives for the second scenario. It can be seen that, the change in the air conditioning strategy affected especially the heating energy consumptions. For instance, while the heating energy consumption of the split core - east and west model reduced 39 per cent with respect to the previous scenario, the cooling energy consumption of the same model reduced 13 per cent.

A comparative summary of the second scenario is presented in Figure 4.6. Similar to the previous scenario, the central core - northeast to southwest model is rated as 100 per cent due to being the most energy consuming alternative, and the other configurations are rated with respect to the this model. The results are quite impressive. According to the simulations, 43 per cent of the total energy consumption of a high-rise building having central core - northeast to southwest configuration can be reduced by adopting the split core - east and west model. The other split core and end core models are also significantly energy efficient. While the split core alternatives provide approximately 40 per cent reduction in energy consumption, the end core models provide approximately 30 per cent energy saving with respect to the central core models.



1- Central core, East-to-West
2- Central core, Southeast-to-Northwest
3- Central core, North-to-South
4- Central core, Northeast-to-Southwest
5- End core, East
6- End core, Southeast
7- End core, South
8- End core, Southwest
9- End core, West
10- End core, Northwest
11- End core, North
12- End core, Northeast
13- Split core, East and West
14- Split core, Southeast and Northwest
15- Split core, North and South
16- Split core, Northeast and Southwest

Figure 4.5. Results of the thermal simulation showing annual heating and cooling energy consumption of the alternatives for scenario 2

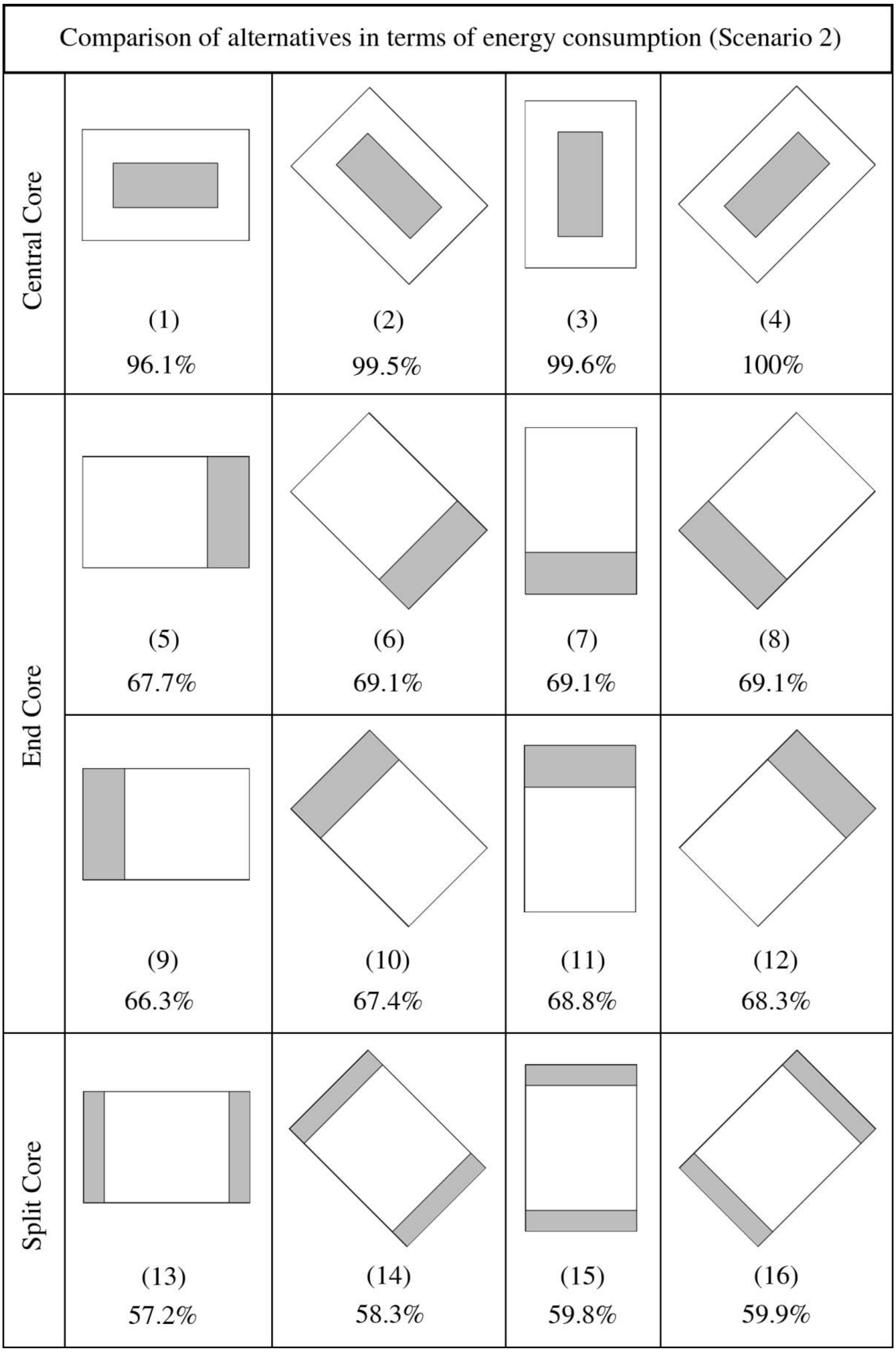


Figure 4.6. Comparative simulation results of the sixteen alternatives for the second scenario

CHAPTER 5

CONCLUSION

Of late, the interest in 'an oil-independent future' and 'sustainability' has increased world-wide. Construction industry has its share of this movement, as the main source of carbon emission in urban areas. Sustainable buildings are built all over the world as an answer to this environmental problem besides to gain prestige upon this new trend.

The relation between sustainability and high-rise buildings is highly complicated. Some people regard high-rises as the solution of the environmental problems owing to the optimization of land use. On the other hand, there are those who criticize these buildings as being important energy consumers due to the high energy demand of their operational systems. At all events, high-rise buildings could be developed further in terms of energy efficiency. Moreover, with inherent potentials of the typology, sustainable high-rise buildings can be saviors of the future urban centers.

Renewable material application, orientation with respect to sun, and introduction of alternative energy supplies are the major strategies of sustainable buildings. However, high-rise buildings have an extra building component with a great potential which is the service core. In this research, service core is examined in terms of sustainability of high-rise buildings. The optimization of the energy consumption of high-rise office buildings is investigated according to several service core configurations.

Sixteen alternative configurations are examined to understand the effect of service core configuration on the energy consumption of high-rise buildings. The alternatives are designed by considering the Sekkei's study (Yeang, 1999), related standards in literature and Turkish regulations. All of the alternative buildings share the same height, floor area, floor efficiency, construction materials, occupation, and operation schedules. They just vary in type and location of the service cores, and orientation of the building mass.

The research methodology uses a thermal simulation program, *eQUEST*, to assess the alternative models. The simulations cover a full year period, and are conducted according to two scenarios. In the first scenario, office and core zones of the hypothetical buildings are treated in the same way in terms heating, cooling and ventilation. In the second scenario, core zones of the end and split core configurations are left as passive zones, and the HVAC is applied only to the office zones of these alternatives; while the central core alternatives are simulated likewise with the previous scenario. According to the simulations, the central core - northeast to southwest model shows the highest energy demand for both of the scenarios. On the contrary, the split core - east and west model has the lowest energy consumption values for both of the scenarios.

The aim of the study is not just to find the most sustainable configuration. The aim is to provide a design guide in which all the alternative configurations are assessed and put forward in comparison among each other. Designing a building is a multi-approach process in which the designer should consider the climate, culture, existent urban fabric, budget, direction of the important vistas, etc. In this process some other design inputs like land dimensions, and existence of a sea scope could not allow to apply the most sustainable configuration. For this reason, the designer should be able to observe all the alternatives and the corresponding energy consumption results to make the best choice that fit his/her project. In this respect, the computed results are given comparatively with respect to each other in terms of the energy consumption values.

In literature, it is suggested that external service cores act as buffer zones, and can minimize the heat loss and/or gain by applying an appropriate configuration with respect to sun and climate of the locality. The results of this dissertation show that there could be important savings up to 43 per cent in energy consumption by adopting an appropriate service core configuration. However, contrary to the related data in literature, the major difference is not resulted from the orientation of buildings or locating the service cores in the coldest/hottest sides. Yet, type of the service core accounts for the major differences in the energy consumption. For instance, the highest difference resultant of the orientation is 3.5 per cent which is between the end core - south and end core - west models. In general, while the split core models are visibly more efficient than the other configurations, the central core alternatives have the highest energy demand due to the great amount of glass surfaces, as can be predicted. End core models are also significantly more efficient than the central core alternatives.

Another objective of the research is to verify the Sekkei's study (Yeang, 1999). Although the study of Sekkei offers a creative look into the issue, some parts of the results are criticized as being contradictious. First of all, as discussed under the section numbered by 2.5.3.4, the minor differences in the energy consumption results of external core models appear suspicious. The reason is that while there is a substantial difference between the energy consumptions of central and external core models, it is expected a greater difference between the split and end core models by supposing that the main reasons of the reduction in cooling load are the reduction in glass façade area and the buffer zone effect rather than orientation of building mass. The results of this study are parallel with this criticism. While there is only a 2 per cent difference between those core types in the Sekkei's work, there is an approximately 10 per cent difference according to this dissertation. Secondly, as mentioned previously, the irrationalities in the Sekkei's work about the effect of building orientation are criticized. The results of this study are rational in terms of this criticism.

This research gives an insight to the importance of service core configuration, and could be a platform for future studies. In this study, the service core is considered as a object that can be replaced from center of a building to peripheral locations without affecting the rest of the building. Future research will be needed to explore the effect of the service core configuration on the other issues such as structural feasibility, functioning of the office zone, efficiency of the building. Moreover, the internal configuration of the service core components with reference to different core types can be scope for future study. Additionally, in this dissertation the energy consumptions are only examined with respect to the buildings' operational systems. However, this can be extended to include the embodied energy consumptions changing with the service core configuration.

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APPENDIX A

BİNALARDA ISI YALITIMI YÖNETMELİĞİ

BİRİNCİ BÖLÜM
Amaç, Kapsam ve Dayanak

Amaç ve kapsam

MADDE 1 – (1) Bu Yönetmeliğin amacı; binalardaki ısı kayıplarının azaltılmasına, enerji tasarrufu sağlanmasına ve uygulamaya dair usul ve esasları düzenlemektir.

(2) Bu Yönetmelik, 10/7/2004 tarihli ve 5216 sayılı Büyükşehir Belediyesi Kanunu kapsamındaki belediyeler dahil olmak üzere, bütün yerleşim birimlerindeki binalarda uygulanır.

(3) Münferit olarak inşa edilen ve ısıtılmasına gerek duyulmayan depo, cephanelik, ardiye, ahır, ağıl ve benzeri binalarda bu Yönetmelik hükümlerinin uygulanması zorunlu değildir.

(4) 180 sayılı Bayındırlık ve İskân Bakanlığının Teşkilat ve Görevleri Hakkındaki Kanun Hükmünde Kararnamenin 32 nci maddesi kapsamına giren kamu kurum ve kuruluşları, il özel idareleri ve belediyeler, bu Yönetmeliğe uymak ve bu Yönetmeliği uygulamakla yükümlüdürler.

Dayanak

MADDE 2 – (1) Bu Yönetmelik, 13/12/1983 tarihli ve 180 sayılı Bayındırlık ve İskân Bakanlığının Teşkilat ve Görevleri Hakkındaki Kanun Hükmünde

Kararnamenin 2 nci maddesinin birinci fıkrasının (a) bendi ile 30/A maddesine dayanılarak hazırlanmıştır.

İKİNCİ BÖLÜM
Projelendirme Genel Esasları

Isı bölgeleri

MADDE 3 – (1) Türkiyede binalarda ısı yalıtımı uygulamaları bakımından oluşturulan dört bölgede yer alan il ve ilçeler EK 1-A'da listede ve EK 1-B'de harita üzerinde gösterilmiştir. Listede yer almayan belediyeler, bağlı oldukları ilçe değerlerini esas alır.

(2) Birinci bölgede yapılacak olan binalarda, merkezi klima sistemi uygulanacak ise, bu binalarda yapılacak olan ısı yalıtımı projesinde, EK-2/C'de yer alan tabloda tavsiye edilen "U" değerlerinden, ikinci bölge için olan "U" değerleri geçerli olur.

Yıllık ısıtma enerjisi ihtiyacı

MADDE 4 – (1) Binalar, ısı kayıpları bakımından çevre şartlarına ve ihtiyaçlarına uygun olarak yalıtılır. Binaların hesaplanan yıllık ısıtma enerjisi ihtiyacı, EK 2-A ve EK 2-B'de bölgelere göre verilen yıllık ısıtma enerjisi sınır değerlerini aşamaz.

İç sıcaklık değerleri

MADDE 5 – (1) Farklı amaçlarla kullanılan binalar için TS 825 hesaplamalarında kullanılacak aylık ortalama iç sıcaklık değerleri [0i (°C)], aşağıdaki tablodan alınır.

Isı geçirgenlik katsayıları

MADDE 6 – (1) Isı yalıtımı hesabı yapılan yeni binalarda, ısıtılan hacimleri ayıran duvar, döşeme ve/veya taban ile tavan ve/veya çatılar için alınacak "U"

Tablo A.1. Aylık ortalama iç sıcaklık değerleri

	Istılacak binanın türü	Sıcaklığı (°C)
1	Konutlar	19
2	Yönetim binaları	
3	İş ve hizmet binaları	
4	Otel, motel ve lokantalar	20
5	Öğretim binaları	
6	Tiyatro ve konser salonları	
7	Kışlalar	
8	Ceza ve tutuk evleri	
9	Müze ve galeriler	
10	Hava limanları	
11	Hastaneler	22
12	Yüzme havuzları	26
13	İmalat ve atölye mahalleri	16

değerlerinin EK 2-C de yer alan tablodaki tavsiye edilen değerlerden büyük olmaması tercih edilir. Ancak bunlardan herhangi biri veya birkaçının, EK 2-C'de yer alan tablodaki tavsiye edilen değerlerden % 25 daha büyük olması durumunda, binanın ısı balansının korunması amacıyla, diğer "U" değerlerinden bir ya da birkaçı için seçilecek olan değerler, EK 2-C de yer alan tablodaki tavsiye edilen değerlerin %25'inden daha küçük olamaz. Ancak bu durumda yapılacak olan hesaplamalar neticesinde hesaplanan (Q) Yıllık Isıtma Enerjisi İhtiyacının, EK-2/A ve B'de verilen (Q') Sınırlandırılan Yıllık Isıtma Enerjisi İhtiyacından küçük olduğu (Q'>Q) gösterilmelidir.

Proje zorunluluğu

MADDE 7 – (1) Bu Yönetmelik hükümleri uyarınca TS 825 Standardında belirtilen hesap metoduna göre yetkili makina mühendisi tarafından mimari proje sistem detaylarına uygun olarak hazırlanan "ısı yalıtımı projesi" imar mevzuatı gereğince yapı ruhsatı verilmesi safhasında ısıtma/soğutma tesisat projesi ile birlikte ilgili idarelerce istenir.

Özel durumlar

MADDE 8 – (1) Belediye sınırları ve mücavir alanlar içindeki mevcut binalarda, ısı yalıtımı yapılacaksa, TS 825'de belirtilen hesap metodu kullanılarak binanın ısı yalıtımı projesi hazırlanmalıdır. Bunun dışındaki özel durumlar için dikkat edilecek hususlar aşağıdaki gibidir.

a) Belediye hudutları ve mücavir alan sınırları dışında, köy nüfusuna kayıtlı ve köyde sürekli oturanların köy yerleşik alanları civarında ve mezralarda 2 kat'a kadar olan ve toplam döşeme alanı 100 m2'den küçük (dış havaya açık balkon, teras, merdiven, geçit, aydınlık ve benzerleri hariç olmak üzere) yeni binalar ile bu alanlardaki mevcut binalarda;

1. Yapı bileşenlerinin, ısı geçirgenlik katsayılarının (U) EK 2/C'deki tavsiye edilen "U" değerlerine eşit veya daha küçük olması,
2. Toplam pencere alanının, ısı kaybeden dış duvar alanının %12'sine eşit veya daha küçük olması şartlarını sağlayan konstrüksiyonlar ve detayların mimari projede gösterilmesi halinde, 7'nci maddede belirtilen "Isı Yalıtımı Projesi" yapılması şartı aranmaz. Bu durumda, yukarıdaki şartların sağlandığını gösteren bir "Isı Yalıtımı Raporu" düzenlenmesi yeterlidir. Ancak, herhangi bir "U" değerinin EK 2/C'deki tavsiye edilen "U" değerlerinden daha büyük olması halinde, bu binalar için ısı yalıtımı projesi hazırlanır.

b) Binanın ısı kaybeden düşey dış yüzeyleri toplam alanının % 60'ı ve üzerindeki oranlarda camlama yapılan binalarda, pencere sisteminin ısı geçirgenlik katsayısının (Up) 2,1 W/m^2K veya bundan daha düşük değerde tasarımlanması ve diğer ısı kaybeden bölümlerinin ısı geçirgenlik katsayılarının EK 2/C'deki tavsiye edilen "U" değerlerinden % 25 daha küçük olmasının sağlanması halinde, bu binalar standarda uygun kabul edilir. Bu tür cam yüzeyi fazla olan binalar için ısı yalıtımı projesi ve hesaplamalar aynen yapılmalı ve bu hesaplamalar içerisinde, yukarıdaki belirtilen şartların yerine getirildiği ayrıca gösterilmelidir. Bununla birlikte, yaz aylarındaki istenmeyen güneş enerjisi kazançları da tasarım sırasında dikkate alınır.

c) Çok katlı olarak inşa edilecek ve bağımsız veya merkezi sistemle ısıtılacak olan binalardaki bağımsız bölümlerin ara döşemeleri ile komşu duvarları; ısıtılmayan iç hacimlere bitişik taban ve duvar gibi düşünülerek, Isı geçirgenlik direnci en az R=0,8 m2K/ W olacak şekilde hesaplanır ve yalıtılır. Bu hesaplama, binanın iç ısı alışverişi kapsamında değerlendirileceğinden ısıtma enerjisi ihtiyacı (Q) hesaplamalarında dikkate alınmaz.

ç) Merkezi sistem ile ısıtılan binalardaki sıcak akışkanı ileten ana dağıtım (tesisat) boruları ve kolonlar, ekonomik yalıtım kalınlığı hesaplanarak uygun şekilde yalıtılır.

d) Kolon kalınlıklarının hesaplanmasında kolonun bağlı bulunduğu kiriş ile birleştiği yerdeki betonarme kiriş kalınlığı aynı zamanda kolon kalınlığı olarak alınır ve kolon kalınlığının kiriş kalınlığından daha fazla olması dikkate alınmaz.

e) Dış yüzeylerde yer alan bütün betonarme elemanlar (kolon, kiriş, hatıl ve perde duvar) yalıtılır. Dolgu duvarlar ise, hesap sonuçlarına göre gerekiyorsa yalıtılır.

Projede bulunması istenilen belgeler

MADDE 9 – (1) Isı yalıtımı projesinde aşağıda belirtilen bilgiler bulunmalıdır.
a) Isı kayıpları, ısı kazançları, kazanç/kayıp oranı, kazanç kullanım faktörü ve aylık ve yıllık ısıtma enerjisi ihtiyacının büyüklükleri, TS 825'de verilen "Binanın Özgül Isı Kaybı" ve "Yıllık Isıtma Enerjisi İhtiyacı" çizelgelerindeki örneklerde olduğu gibi çizelgeler halinde verilir ve hesaplanan yıllık ısıtma enerjisi ihtiyacının (Q), EK 2-B'deki sınırlandırılan yıllık ısıtma enerjisi ihtiyacı (Q’) formülünden elde edilecek olan sınır değerden büyük olmadığı gösterilir.

b) Konutlar dışında farklı amaçlarla kullanılan binalar için yapılacak hesaplamalarda, binadaki farklı bölümler arasındaki sıcaklık farkı 4°K'den daha fazla ve bu binada birden fazla bölüm için yıllık ısıtma enerjisi ihtiyacı hesabı yapılacak ise, bu bölümlerin sınırları şematik olarak çizilir, sınırların ölçüleri ve bölümlerin sıcaklık değerleri üzerinde gösterilir.

c) Binanın ısı kaybeden yüzeylerindeki dış duvar, tavan, taban/döşemelerde kullanılan malzemeler, bu malzemelerin eleman içindeki sıralanışı ve kalınlıkları, duvar, tavan, taban/döşeme elemanlarının alanları ve "U" değerleri belirtilir.

ç) Pencere sistemlerinde kullanılan cam ve çerçevenin tipi, bütün yönler için ayrı ayrı pencere alanları ve "U" değerleri ile çerçeve sistemi için gerekli olan hava değişim sayısı (nh) belirtilir.

d) Duvar-pencere, duvar-tavan, taban-döşeme-duvar birleşim yerlerine ait mimari proje kesit detayları verilmelidir.

e) Havalandırma tipi ve mekanik havalandırma sözkonusu ise, hesaplamalar ve sonuçları gösterilmelidir.

f) Isı yalıtımı projesinde, binanın ısı kaybeden yüzeylerinde meydana gelebilecek olan yoğuşma TS 825-EK F'de belirtilen şekilde tahkik edilir.

g) Mevcut binaların tamamında veya bağımsız bölümlerindeki yapılacak olan esaslı tamir, tadil ve eklemelerdeki uygulama yapılacak olan bölümler için, TS 825'te verilen ısı geçirgenlik katsayılarının EK-2/C'deki tavsiye edilen en yüksek "U" değerlerine eşit ya da bu değerlerden daha küçük değerde olması sağlanmalıdır.

ğ) TS 825'te belirtilen hesap metodunun kullanılması sırasında gerekli olan bilgiler, (yoğuşma hesabı da dâhil olmak üzere) TS 825 standardından (EK A - EK J) temin edilir.

h) Bitişik nizam olarak (sıra evler, ikiz evler) projelendirilmiş olan binaların, ısıtma enerjisi ihtiyacı (Q) hesabı yapılırken, komşu bina ile bitişik duvar olan bölümleri de dış duvar gibi değerlendirilir ve hesaba katılır.
ı) Bu maddede belirtilmeyen diğer hususlar hakkında TS 825 Mayıs 2008'e uyulur.

Isı yalıtımı detayları

MADDE 10 – (1) Mimari proje düzenlenirken, ısı yalıtımı detaylarının hazırlanmasında yol gösterici olması amacıyla ısı yalıtımı detayları EK 4'te verilmiştir.

(2) Yapılacak hesaplar sonunda bulunacak yapı malzemesi kalınlıklarına göre detaylar kesinleştirilir.

(3) Yapı ve yalıtım malzemelerinin temasında (detayda) farklı "U" değerlerinden kaynaklanan ısı köprülerinin
meydana gelmemesi için, yalıtım sırasında gereken tedbirler alınır.

(4) Teknolojik gelişmelere göre standartlarda yer alacak yeni malzemeler de detaylarda kullanılabilir.

Mimari uygulama projesi

MADDE 11 – (1) Mimari uygulama projesi; sistem detaylarını, nokta detaylarını ve çatı-duvar, duvar-pencere ve taban-döşeme-duvar bileşim detaylarını ihtiva etmelidir. Isı yalıtımı projesi, mimari uygulama projesindeki detaylarda belirtilen malzemeler ve kalınlıklarına (yalıtım malzemesi hariç) göre hazırlanmalıdır.

Isı ihtiyacı kimlik belgesi

MADDE 12 – (1) EK 3'te örneği verilen "Isı İhtiyacı Kimlik Belgesi", yetkili ısı yalıtımı projecisi ve uygulamayı yapan makina mühendisleri tarafından doldurulup imzalandıktan ve Belediye veya Valilik tarafından onaylandıktan sonra yapı kullanma izin belgesine eklenmelidir. Bu belge, bina yöneticisinin dosyasında bulundurulur ve bir kopyası da bina girişine asılır.

ÜÇÜNCÜ BÖLÜM

Kaloriferli Binalara Dair Uygulama Esasları

Kazan daireleri

MADDE 13 – (1) Kazan dairesi yapımında aşağıdaki hususlara uyulur:

a) Kazan dairelerinin boyutları, yakıt cinsine göre belirlenir.

b) Kazan daireleri, bir adet bina içine ve bir adet direkt bina dışına açılan, olmak üzere iki adet kapısı olacak şekilde düzenlenmelidir.

c) Kazan dairesinin kapıları yanmaz malzemeden yapılır ve doğrudan merdiven boşluğuna açılmamalıdır. Koku, sızıntı ve yangın halinde, dumanın bina içine girmesini engellemek üzere arada küçük bir giriş odası yapılır ve bu odanın kapıları sızdırmaz özellikte olur ve alta eşik konulmalıdır.

ç) Kazanların önü ve arkası ile sağ ve sol yanında, her türlü bakım onarım ve müdahalenin yapılmasına imkan sağlayacak açıklık bulunur.

d) Kazan dairesinde, yakıt türüne göre gereken temiz havayı temin etmek ve egzoz havasını atmak üzere uygun havalandırma sağlanır.

e) Kazan dairesinin dış duvarının olması veya ısı merkezinin ayrı bir binada bulunması halinde, doğal havalandırmanın sağlanabilmesi için kazan dairesi taban alanının en az 1/12'si kadar dış duvarlara pencere konulur.

f) Temiz hava giriş menfezi zemin düzeyinde ve Egzoz (pis hava atma) bacası ağzının ise tavan düzeyinde olması sağlanır.

g) Katı ve sıvı yakıt kullanılan tesiste taze hava giriş menfezi kesiti, duman bacası kesitinin % 50'sinden az olmamak üzere 50 kW (43000 kcal/h)'a kadar 300 cm^2, sonraki her kW için 2,5 cm^2 ilave edilerek bulunur. Egzoz bacası kesiti ise duman bacası kesitinin % 25'i kadar olmalıdır.

ğ) Gaz yakıtlı kazanlarda temiz hava giriş menfezi, duman bacası ve egzoz bacası kesitleri gaz firmaları ve ilgili gaz dağıtım kuruluşlarının istediği usul ve hesap değerlerine göre belirlenir. Kazan dairelerinde doğal havalandırma yapılamayan hallerde cebri havalandırma uygulanır. Bu durumda;

1. Sıvı yakıtta bu havalandırma kapasitesi kazanın her kW'ı için 0,5 m^3/h olmalı.
2. Cebri havalandırmalı sıvı yakıtlı kazan dairelerinde;
   Vantilatör kapasitesi = (Brülör fan kapasitesi + aspiratör kapasitesi) x 1,1 olmalı ve fanın brülör ile aynı anda birlikte çalışması sağlanmalıdır.
3. Katı yakıt kullanılan teshin merkezlerinde mutlaka doğal havalandırma yapılır.
4. Gaz yakıtlı kazan dairelerinde havalandırma seçimi, gaz firmaları ile gaz dağıtım kuruluşlarının kriterlerine göre yapılır. Sadece emiş veya egzoz yapılan yarı cebri havalandırmalı kazan dairelerinde negatif basınç oluşacağından bu tür sistemler uygulanmaz.

h) Kazan dairesinde farklı yakıtlı kazanlar var ise, en yüksek değerdeki baca ve havalandırma kriterleri esas alınır.

ı) Soğuk bölgelerde ve sürekli kullanılmayan kazan dairelerinde donmaya karşı tedbir olarak havalandırma panjurlarını otomatik kapayan donanım yapılır.

i) Kazan dairesi yüksekliği TS 2192' ye göre hesaplanır.

j) Kazan kullanıcılarının kullanılan yakıt cinsine göre eğitimleri yaptırılarak sertifikalandırılmaları sağlanır.

k) Sıvı veya gaz yakıt kullanılan kazan olması durumunda, gerekli tedbirleri almak koşuluyla, kazan daireleri çatıda tesis edilebilir. Bu durumda;

1. Statik hesaplarda kazan dairesi etkisi dikkate alınmalıdır. (Yaklaşık 1000-2000 kg/m^2)
2. Çatının altında ve yanındaki mahallere rahatsızlık verebilecek etkileri aktarmamak için yeterli ses yalıtımı uygulanmalıdır. Kazanların altına titreşim izoleli kaide yapılmalıdır.
3. Kazan dairesinden çıkış için uygun merdiven yapılmalıdır. Kapı ve pencereler kaçış yönünde, kilitsiz ve kolay açılabilecek şekilde düzenlenmelidir.
4. Yakıt boru hattı, doğal havalandırmalı, kolay müdahale edilebilen bir dikey tesisat kanalı veya merdiven boşluğunda duvara yakın olacak şekilde düzenlenmelidir.
5. Havalandırma ve diğer hususlardaki kriterler, bodrum katındaki kazan daireleri ile aynı olmalıdır.

Bacalar

MADDE 14 – (1) Bacaların yapımında aşağıdaki hususlara uyulur:
a) Her kazan için standardına uygun ayrı bir baca yapılır. Ancak, gaz yakıtlı kazan bacalarında, gaz firmaları veya gaz dağıtım kuruluşlarınca önerilen kriterlere göre ortak baca uygulanabilir.

b) Kazan bacalarına, şofben, kombi, kat kaloriferi ve jeneratör gibi başka cihaz bacalarının bağlantısı yapılmaz.

c) Bacalar, mümkünse bina içinde olmalıdır. Zorunlu hallerde, bacanın bina dışında yapılması halinde, soğumaması için gerekli ısı yalıtımı ve dış koruması yapılmalıdır.
ç) Katı ve sıvı yakıtlı kazanlarda bacalar dolu tuğla (içi sıvalı) veya ateş tuğlası ile, gaz yakıtlı kazanlarda ise baca ısıya, yoğuşma etkilerine dayanıklı malzemelerden ve uygun üretim teknikleri ile yapılmalıdır. Metal bacalarda yanma sesinin yukarılara iletilmemesi için gerekli tedbirler alınmalı ve baca topraklaması yapılmalıdır.

d) Bacaların en altında bir temizleme kapağı bulunmalıdır.

e) Gaz yakıtlı kazanlarda, temizleme kapağına ek olarak drenaj düzeni yapılır.

f) Bacalar, yanlarındaki bina ve engellerden etkilenmeyecek şekilde tesis edilir; bu engellerin en üst noktasından veya münferit binalarda mahya kotundan en az 1 m yükseklikte olur ve üzerine şapka yapılır.

g) Bacalar, mümkün olduğunca dik yapılmalı, zorunlu hallerde ise yatayla en az 60° açıda tek sapmaya izin verilmelidir.

ğ) Duman kanalları, çelik malzemeden yapılır ve izole edilir. Gaz yakıtlı kazanlarda paslanmaz çelik tercih edilir. Kanallar, kolayca temizlenecek şekilde düzenlenir ve gaz analizi için üzerinde ölçüm delikleri bırakılır. Duman kanallarının yatay uzunluğu dikey bacanın 1/4'ünden daha fazla olmaz; kanal ana bacaya direkt ve % 5'lik yükselen eğimle bağlanır, 2 adet 45°'lik dirsekten fazla sapma olmaz ve 90°'lik dirsek kesinlikle kullanılamaz.

h) Baca ve duman kanallarında uygun yalıtım malzemeleri kullanılır.

ı) Yüksek binaların bacalarında, genleşme ve bacanın kendini taşıması için gerekli tedbirler alınır.

i) Baca kesiti zorunlu olmadıkça dairesel olması gerekir.

Radyatörler

MADDE 15 – (1) Dış duvarlara monte edilen radyatörlerin arkasına, üzeri yansıtıcı levha veya film kaplanmış yalıtım panelleri konulur.

Otomatik kontrol

MADDE 16 – (1) Yakıt tasarrufu için sıvı ve gaz yakıtlı kazanlarda otomatik kontrol sistemi tercih edilir. Gaz firmaları ve ilgili gaz dağıtım kuruluşlarınca belirlenen esaslara göre, ayrıca gaz kaçak kontrol sistemi tesis edilir.

DÖRDÜNCÜ BÖLÜM
Çeşitli ve Son Hükümler

Yapı ve yalıtım malzemelerinin standarda uygunluğu

MADDE 17 – (1) Yapı ve yalıtım malzemelerinin ısıl iletkenlik hesap değerleri TS 825 EK - E'de verilmiş olup, Isı yalıtımı projesi burada verilen değerlere göre hesaplanır. Bina yapımında kullanılacak yapı ve yalıtım malzemeleri için 8/9/2002 tarihli ve 24870 sayılı Resmî Gazete'de yayımlanan Yapı Malzemeleri Yönetmeliği çerçevesinde, yapı ve yalıtım malzemelerinin CE veya G uygunluk işareti ve uygunluk beyanı veya belgesi olması zorunludur.

(2) Birinci fıkra hükümleri çerçevesinde beyan edilen ısıl iletkenlik hesap değerlerinin TS 825 EK-E'deki değerlerden daha küçük olması ve bu değerin hesaplamalarda kullanılmak istenmesi halinde, bu tür malzemelerin değerleri için aynı hesap yöntemi kullanılır. Bu tür malzemelerin, beyan edilen ısıl iletkenlik hesap değerlerinin hesaplamalarda kullanılabilmesi için, Bayındırlık ve İskân Bakanlığınca bu amaç için özel olarak görevlendirilmiş bir kuruluş tarafından, malzemenin beyan edilen ısıl iletkenlik hesap değerlerinin belgelendirilmesi şarttır. Eğer bu belgelendirme yapılmamışsa, hesaplamalarda, söz konusu malzemenin beyan edilen ısıl iletkenlik hesap değeri yerine TS 825 EK-E 'deki

değerler alınır. Bu kuruluşun çalışma usul ve esasları Bayındırlık ve İskân Bakanlığınca belirlenir.

Isı yalıtımı denetimi

MADDE 18 – (1) İnşaatın her safhasında ısı yalıtımı ile ilgili denetimler 29/6/2001 tarihli ve 4708 sayılı Yapı Denetim Hakkında Kanun kapsamındaki illerde, yapı denetim kuruluşları ile beraber belediye sınırları ve mücavir alanlarda belediyeler; belediye ve mücavir alan sınırları dışında il özel idareleri ve ruhsat verme yetkisine sahip diğer idarelerce yapılır.

(2) Binanın ısı yalıtımının kontrolü ile ilgili teknik sorumlu; inşaatın taban, döşeme, duvar ve tavan yapımı safhalarında uygulanan yalıtımın, projede verilen detaylara uygunluğunun kontrolünü yaparak, belediye veya il özel idarelerine rapor verir.

Yürürlükten kaldırılan yönetmelik

MADDE 19 – (1) 8/5/2000 tarihli ve 24043 sayılı Resmî Gazete'de yayımlanan Binalarda Isı Yalıtım Yönetmeliği yürürlükten kaldırılmıştır.

Yapım işi ihalesi ilan edilmiş olan kamu binaları ve yapı ruhsatı alınmış özel binalar

GEÇİCİ MADDE 1 – (1) Bu Yönetmeliğin yürürlüğe giriş tarihinden önce yapım işi ihalesi ilan edilmiş olan kamu binaları ve yapı ruhsatı alınmış özel binalar hakkında bu Yönetmelik hükümleri uygulanmaz.

Yürürlük

MADDE 20 – (1) Bu Yönetmelik 1/11/2008 tarihinde yürürlüğe girer.

Yürütme

MADDE 21 – (1) Bu Yönetmelik hükümlerini Bayındırlık ve İskân Bakanı yürütür.

Tablo A.2. Ek 1-A, illere göre derece gün bölgeleri

1. Bölge Derece Gün İlleri

Adana	Aydın	Mersin	Osmaniye
Antalya	Hatay	İzmir	

İli 2. Bölgede olup da kendisi 1. Bölgede olan belediyeler

Ayvalık (Balıkesir)	Dalaman (Muğla)	Fethiye (Muğla)
Bodrum (Muğla)	Datça (Muğla)	Köyceğiz (Muğla)
Gökova (Muğla)	Marmaris (Muğla)	Milas (Muğla)

2. Bölge Derece Gün İlleri

Adıyaman	Denizli	Kilis	Rize	Şırnak
Amasya	Diyarbakır	Kocaeli	Sakarya	Tekirdağ
Balıkesir	Edirne	Manisa	Samsun	Trabzon
Bartın	Gaziantep	Mardin	Siirt	Yalova
Batman	Giresun	Muğla	Sinop	Zonguldak
Bursa	İstanbul	Ordu	Şanlıurfa	Düzce
Çanakkale	K.Maraş			

İli 3. Bölgede olup da kendisi 2. Bölgede olan belediyeler

Hopa (Artvin)	Arhavi (Artvin)

İli 4. Bölgede olup da kendisi 2. Bölgede olan belediyeler

Abana (Kastamonu)	Bozkurt (Kastamonu)	Çatalzeytin (Kastamonu)
İnebolu (Kastamonu)	Cide(Kastamonu)	Doğanyurt (Kastamonu)

3. Bölge Derece Gün İlleri

Afyon	Bolu	Iğdır	Kırşehir	Tokat
Aksaray	Burdur	Isparta	Konya	Tunceli
Ankara	Çankırı	Karabük	Kütahya	Uşak
Artvin	Çorum	Karaman	Malatya	
Bilecik	Elazığ	Kırıkkale	Nevşehir	
Bingöl	Eskişehir	Kırklareli	Niğde	

İli 1. Bölgede olup da kendisi 3. Bölgede olan belediyeler

Pozantı (Adana)	Korkuteli (Antalya)

İli 4. Bölgede olup da kendisi 3. Bölgede olan belediyeler

Merzifon (Amasya)	Dursunbey (Balıkesir)	Ulus (Bartın)

4. Bölge Derece Gün İlleri

Ağrı	Bitlis	Gümüşhane	Kastamonu	Sivas
Ardahan	Erzincan	Hakkari	Kayseri	Van
Bayburt	Erzurum	Kars	Muş	Yozgat

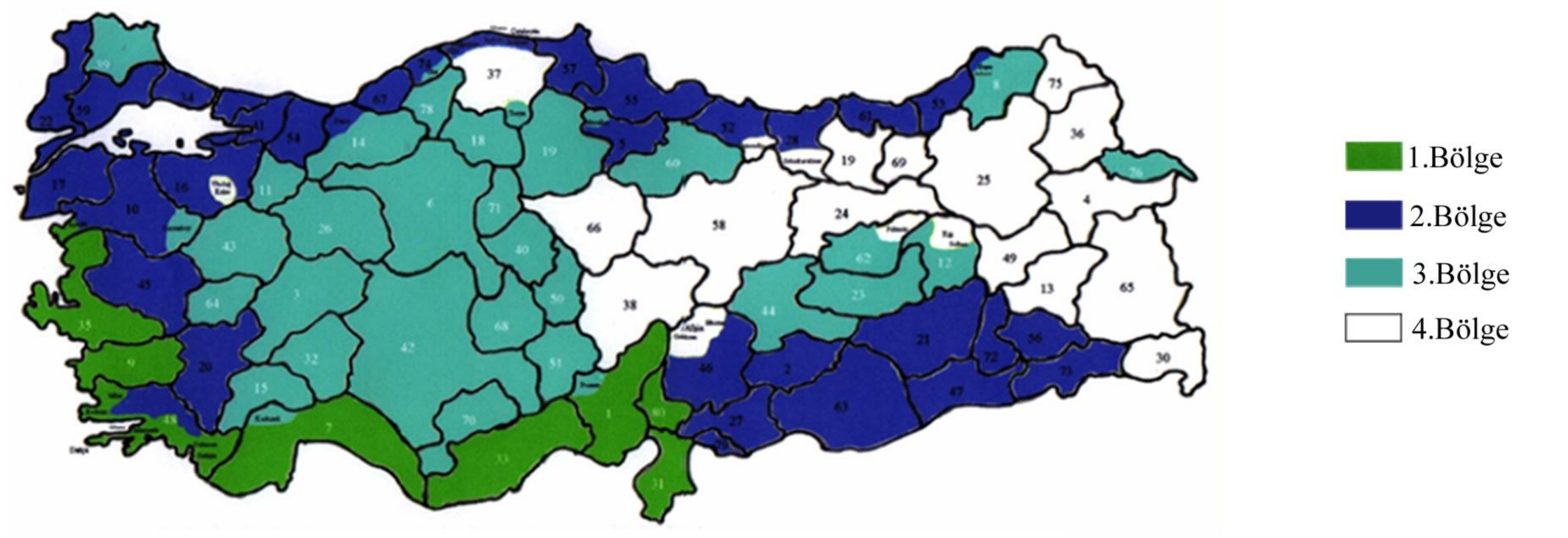
İli 2. Bölgede olup da kendisi 4. Bölgede olan belediyeler

Keles (Bursa)	Afşin (K.Maraş)	Mesudiye (Ordu)
Uludağ (Bursa)	Göksun (K.Maraş)	
Şebinkarahisar (Giresun)	Elbistan (K.Maraş)	

İli 3. Bölgede olup da kendisi 4. Bölgede olan belediyeler

Kığı (Bingöl)	Pülümür (Tunceli)	Solhan (Bingöl)

Not - Ek'te adı bulunmayan yerleşim birimleri, bağlı bulundukları belediyenin bölgesinde sayılır.



01-Adana	12-Bingöl	23-Elazığ	34-İstanbul	45-Manisa	56-Siirt	67-Zonguldak	78- Karabük
02-Adıyaman	13-Bitlis	24-Erzincan	35-İzmir	46-K.Maraş	57-Sinop	68-Aksaray	79- Kilis
03-Afyon	14-Bolu	25-Erzurum	36-Kars	47-Mardin	58-Sivas	69-Bayburt	80- Osmaniye
04-Ağrı	15-Burdur	26-Eskişehir	37-Kastamonu	48-Muğla	59-Tekirdağ	70-Karaman	81- Düzce
05-Amasya	16-Bursa	27-Gaziantep	38-Kayseri	49-Muş	60-Tokat	71-Kırıkkale	
06-Ankara	17-Çanakkkale	28-Giresun	39-Kırklareli	50-Nevşehir	61-Trabzon	72-Batman	
07-Antalya	18-Çankırı	29-Gümüşhane	40-Kırşehir	51-Niğde	62-Tunceli	73- Şırnak	
08-Artvin	19-Çorum	30-Hakkari	41-Kocaeli	52-Ordu	63-Şanlıurfa	74- Bartın	
09-Aydın	20-Denizli	31-Hatay	42-Konya	53-Rize	64-Uşak	75- Ardahan	
10-Balıkesir	21-Diyarbakır	32-Isparta	43-Kütahya	54-Sakarya	65-Van	76- Iğdır	
11-Bilecik	22-Edirne	33-İçel	44-Malatya	55-Samsun	66-Yozgat	77- Yalova	

Figür A.1. Ek 1-B, derece gün bölgelerine göre iller

Tablo A.3. Ek 2-A, En büyük ve en küçük Atop/Vbrüt oranları için ısıtma enerjisi değerleri

		A/V< 0.2 için	A/V>1.05 için	
1. Bölge	A_n ile ilişkili $Q'_{1.DG}$=	19.2	56.7	kWh/m³,yıl
	$A_{brüt}$ ile ilişkili $Q'_{1.DG}$=	6.2	18.2	kWh/m³,yıl
2. Bölge	A_n ile ilişkili $Q'_{2.DG}$=	38.4	97.9	kWh/m³,yıl
	$V_{brüt}$ ile ilişkili $Q'_{2.DG}$=	12.3	31.3	kWh/m³,yıl
3. Bölge	A_n ile ilişkili $Q'_{3.DG}$=	51.7	116.5	kWh/m³,yıl
	$V_{brüt}$ ile ilişkili $Q'_{3.DG}$=	16.6	37.3	kWh/m³,yıl
4. Bölge	A_n ile ilişkili $Q'_{4.DG}$=	67.3	137.6	kWh/m³,yıl
	$V_{brüt}$ ile ilişkili $Q'_{4.DG}$=	21.6	44.1	kWh/m³,yıl

Tablo A.4. Ek 2-B, Bölgelere ve ara değer Atop/Vbrüt oranlarına bağlı olarak sınırlandırılan Q'nun hesaplanması

1. Bölge	A_n ile ilişkili $Q'_{1.DG}$=	44.1	x	A/V	+	10.4	[kWh/m³,yıl]
	$V_{brüt}$ ile ilişkili $Q'_{1.DG}$=	14.1	x	A/V	+	3.4	[kWh/m³,yıl]
2. Bölge	A_n ile ilişkili $Q'_{2.DG}$=	70	x	A/V	+	24.4	[kWh/m³,yıl]
	$V_{brüt}$ ile ilişkili $Q'_{2.DG}$=	22.4	x	A/V	+	7.8	[kWh/m³,yıl]
3. Bölge	A_n ile ilişkili $Q'_{3.DG}$=	76.3	x	A/V	+	36.4	[kWh/m³,yıl]
	$V_{brüt}$ ile ilişkili $Q'_{3.DG}$=	24.4	x	A/V	+	11.7	[kWh/m³,yıl]
4. Bölge	A_n ile ilişkili $Q'_{4.DG}$=	82.8	x	A/V	+	50.7	[kWh/m³,yıl]
	$V_{brüt}$ ile ilişkili $Q'_{4.DG}$=	26.5	x	A/V	+	16.3	[kWh/m³,yıl]

Tablo A.5. Ek 2-C, Bölgelere göre en fazla değer olarak kabul edilmesi tavsiye edilen U değerleri

	U_D (W/m²K)	U_T (W/m²K)	U_t (W/m²K)	U_P* (W/m²K)
1. Bölge	0.70	0.45	0.70	2.40
2. Bölge	0.60	0.40	0.60	2.40
3. Bölge	0.50	0.30	0.45	2.40
4. Bölge	0.40	0.25	0.40	2.40

* : Pencerelerin ısıl geçirgenlik katsayıları (U_p), TS 825 Ek A.3'te ve Ek A.4'te verilmiş olup pencerelerden olan ısı kayıplarının en aza indirilmesi açısından U_p değerinin kaplamalı camlar kullanılarak 1,8 W/m2K'e kadar düşürülecek şekilde tasarımlanması tavsiye edilir. Diğer kapı ve pencere türleri için TS 2164'te verilen 11.05.2000 revizyon tarihli Çizelge 6a ve Çizelge 6b kullanılarak ısıl geçirgenlik katsayıları bulunur ve hesaba katılır. Bazı pencere tipleri için TS 2164'ten faydalanılarak bulunan Up değerleri, TS 825 Ek A.4'te verilmiştir.