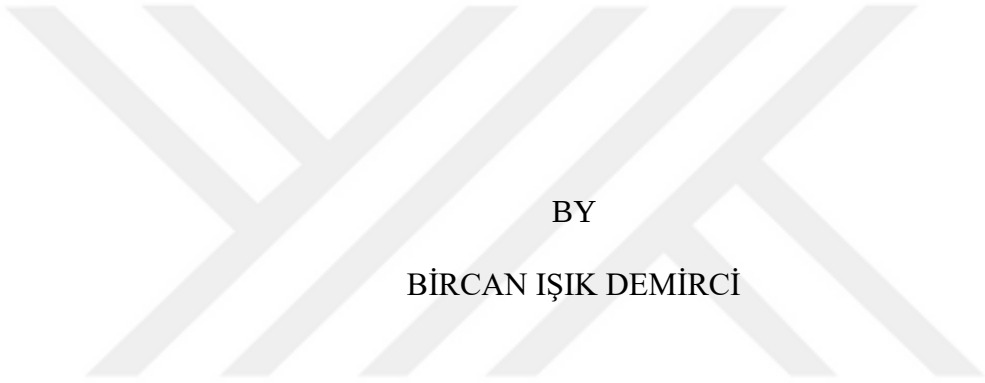


ENERGY PERFORMANCE ANALYSIS
WITH RELEVANCE TO URBAN FORM

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
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WITH RELEVANCE TO URBAN FORM**

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ABSTRACT

ENERGY PERFORMANCE ANALYSIS WITH RELEVANCE TO URBAN FORM

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Urban areas have become the nodal points of the energy problem. Overcoming such points, thus, is essential for responding to the urgent call for the energy transition. This problem manifests itself especially in the buildings, which are a vital element of the energy transition due to their energy-saving and generation potential. As such, the early urban design phase, where energy and environmental quality concerns are typically dealt with, is of utmost importance to reduce the energy use of buildings, increase generating their energy with renewables, and mitigate urban heat island effect. On the other hand, properly integrating energy performance and urban local climate considerations into urban design practices requires a better understanding of the effect of the design decisions.

In this regard, this research focuses on the early design phase of future residential areas to better understand how urban design decisions, particularly those that are related to urban form, affect buildings' energy performance and urban heat island intensity. Thus, it aims to be a step toward integrating energy and urban local climate

considerations into urban design practices to help energy transition. In this framework, this study uses a bottom-up, physics-based approach for energy modeling; and conducts evaluations through a total of 162 simulations in the Grasshopper environment via Dragonfly, Climate Studio, and Colibri. In simulations, parametrically designed hypothetical models were used. Since there are three main climate types in Turkey according to the Köppen-Geiger climate classification system, this study relies on climate data available in three cities; namely İzmir (C), Konya (B), and Van (D) as the representative of these three climate types.

In conclusion, this research states that, considering the energy demands of buildings, more compact forms are advantageous in terms of heating and cooling needs. When the buildings' active solar energy production potential is examined and the balance between the buildings' energy demand and production potential is considered, less compact and less dense urban forms come to the forefront. Furthermore, research findings revealed that urban heat island (UHI) has significant effects on buildings' heating and cooling needs. When UHI was not considered, the annual heating EUI (energy use intensity) increased by 11-18 %; the annual cooling EUI decreased by 19-58 % compared to the situation in which UHI was considered.

Keywords: Energy Performance Analysis, Energy and Urban Form, Performance-driven Urban Design, Parametric Modelling

ÖZ

KENT FORMU ÇERÇEVESİNDE ENERJİ PERFORMANS ANALİZİ

Işık Demirci, Bircan
Yüksek Lisans, Kentsel Tasarım, Şehir Bölge Planlama
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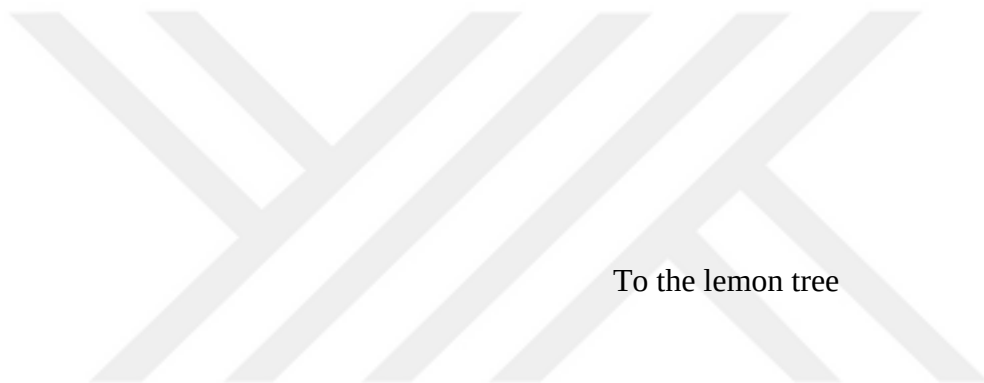
Kentsel alanlar, enerji sorununun düğüm noktaları haline gelmiştir. Bu nedenle, bu tür noktaların üstesinden gelmek, enerji geçişi için yapılan acil çağrıya yanıt vermek için elzemdir. Bu sorun özellikle enerji tasarrufu ve üretim potansiyeli nedeniyle enerji geçişinin hayati bir unsuru olan binalarda kendini göstermektedir. Bu nedenle, enerji ve çevresel kalite sorunlarının tipik olarak ele alındığı erken kentsel tasarım aşaması, binaların enerji kullanımını azaltmak, yenilenebilir enerji ile enerji üretimini artırmak ve kentsel ısı adası etkisini azaltmak için son derece önemlidir. Öte yandan, enerji performansı ve kentsel yerel iklim hususlarının kentsel tasarım uygulamalarına uygun şekilde entegre edilmesi, tasarım kararlarının etkisinin daha iyi anlaşılmasını gerektirir.

Bu bağlamda, bu araştırma, kentsel tasarım kararlarının, özellikle kentsel biçimle ilgili olanların, binaların enerji performansını ve kentsel ısı adası yoğunluğunu nasıl etkilediğini daha iyi anlamak için gelecekteki yerleşim alanlarının erken tasarım aşamasına odaklanmaktadır. Böylelikle, enerji geçişine yardımcı olmak için enerji ve kentsel yerel iklim hususlarını kentsel tasarım uygulamalarına entegre etmeye

yönelik bir adım olmayı hedeflemektedir. Bu çerçevede, bu çalışma, enerji modellemesi için aşağıdan yukarıya, fizik tabanlı bir yaklaşım kullanmaktadır; Dragonfly, Climate Studio ve Colibri aracılığıyla Grasshopper ortamında toplam 162 simülasyon üzerinden değerlendirmeler yapmaktadır. Simülasyonlarda parametrik olarak tasarlanmış varsayımsal modeller kullanılmıştır. Türkiye'de Köppen-Geiger iklim sınıflandırma sistemine göre üç ana iklim tipi bulunduğundan, bu çalışma bu üç iklim tipini temsil eden üç ildeki mevcut iklim verilerine dayanmaktadır; İzmir (C), Konya (B) ve Van (D).

Sonuç olarak bu araştırma, binaların enerji talepleri göz önünde bulundurulduğunda, daha kompakt formların ısıtma ve soğutma ihtiyaçları açısından avantajlı olduğunu belirtmektedir. Binaların aktif güneş enerjisi üretim potansiyeli incelendiğinde ve binaların enerji talebi ile üretim potansiyeli arasındaki denge göz önüne alındığında ise daha az kompakt ve daha az yoğun kentsel formlar ön plana çıkmaktadır. Ayrıca araştırma bulguları, kentsel ısı adasının (KIA) binaların ısıtma ve soğutma ihtiyaçları üzerinde önemli etkileri olduğunu ortaya koymuştur. KIA dikkate alınmadığında, yıllık ısıtma enerji kullanım yoğunluğu %11-18 artmış; yıllık soğutma enerji kullanım yoğunluğu, KIA dikkate alındığı duruma kıyasla %19-58 oranında azalmıştır.

Anahtar Kelimeler: Enerji Performans Analizi, Enerji ve Kent Formu, Performans Odaklı Kentsel Tasarım, Parametrik Modelleme



To the lemon tree

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LIST OF ABBREVIATIONS

BEM	Building Energy Modeling
CEN	European Committee for Standardization
COP	Coefficient of Performance
EPBD	Energy Performance of Buildings Directive
EUI	Energy Use Intensity
FAR	Floor Area Ratio
FSI	Floor Space Index
GSI	Ground Space Index
HVAC	Heating, Ventilating and Air Conditioning
ICLEI	Local Governments for Sustainability
IEA	International Energy Agency
IPCC	The Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IRENA	International Renewable Energy Agency
MoEU	Ministry of Environment and Urbanization
MXI	Mixed-use index
nZEB	Nearly Zero-energy Building
OECD	Organisation for Economic Co-operation and Development
OSR	Open Space Ratio
OSV	Obstruction sky view
PV	Photovoltaics

RES	Renewable-Energy-Sources
SCR	Site Coverage Ratio
SHGC	Solar Heat Gain Coefficient
SVF	Sky view factor
SVT	Surface-to-volume ratio
TSI	Turkish Standard Institution
UBEM	Urban Building Energy Modeling
UHA	Urban Horizon Angle
UHI	Urban Heat Island
UN	United Nations
UNEP	United Nations Environment Program

CHAPTER 1

INTRODUCTION

1.1 Problem Statement

“While a range of human activities causes greenhouse-gas emissions, the biggest cause by far is energy use. The climate change problem is principally an energy problem” (Mackay, 2008). Today building stocks are the largest energy consumers (GlobalABC / IEA / UNEP, 2019) and urban design decisions have a significant effect on buildings’ energy demand (Ratti et al., 2003, 2005; Strømman-Andersen & Sattrup, 2011; Wong et al., 2011; Steemers, 2003; Sattrup & Strømman-Andersen, 2013) and solar energy potential (Cheng et al., 2006; Compagnon, 2004; Hachem et al., 2013; Kanters & Wall, 2014; Knowles, 2003; Mohajeri et al., 2016; Sarralde et al., 2015). Moreover, urban areas create their climate (Hoffmann et al., 2012). They have higher air temperatures compared to the surrounding rural areas, and this phenomenon is called the urban heat island (Oke, 1995) and urban heat island intensity is also affected by urban design decisions (Aiko et al., 2015; Bouyer et al., 2017; Natanian, Maiullari, et al., 2019; Watkins et al., 2007). Therefore, how to design built environments is of importance to tackle energy problems, hence, climate change problem.

Despite the urgent call for an energy transition (IPCC, 2018) and despite building stocks are vital elements of this transition (IRENA, 2016; GlobalABC/IEA/UNEP, 2020), very few things have changed in urban design practices. The current tendency in energy-conscious design practices relies on stand-alone building configurations, yet evaluating buildings as part of settlement areas rather than as isolated structures allow more overarching decisions to be made, as it also takes into account the

interaction of buildings with their surroundings (Ali-toudert, 2009; Allegrini et al., 2012; Dorer et al., 2013; KanTERS & Horvat, 2012a; Naboni et al., 2019; Ratti et al., 2005; Samuelson et al., 2016; Takebayashi et al., 2015; Vandevyvere & Stremke, 2012).

On the other hand, considering the interaction between buildings increases the complexity of the decision-making process (Nault et al., 2015). Thus, properly integrating energy performance and urban local climate considerations into urban design practices require a better understanding of the effect of the design decisions. In other words, to reduce the impact on our environment and enhancing indoor and outdoor environment quality, designers must understand how their decisions impact "real-life" (Miller & Buys, 2012).

The early design phase, where energy and environmental quality concerns are typically dealt with, is a time to make an effort multiple design scenarios, each having distinct advantages and disadvantages regarding the various objectives and various aspects (KanTERS & Wall, 2014; Nault et al., 2015; Samuelson et al., 2016). So, this phase presents the opportunity to reduce the energy use of buildings (Méndez Echenagucia et al., 2015; Samuelson et al., 2016) and to increase generating their energy with renewables (KanTERS, 2015), as well as to mitigate urban heat island effect (Aiko et al., 2015; Natanian, Maiullari, et al., 2019)

In this regard, this research focuses on the early design phase of future urban blocks to better understand how urban design decisions affect buildings' energy performance and urban heat island intensity. The work scope is limited to residential buildings, which account for the largest share of energy use in the building sector (GlobalABC / IEA / UNEP, 2019). Thus, by providing a workflow, aims to be a step toward integrating energy and urban local climate considerations into urban design practices to help energy transition.

Before presenting the research questions, the study's significance is explained, and the required linkages for the questions are established through the following background part.

1.2 Background of the Study

1.2.1 Why Energy Transition is Needed in Urban Areas?

According to the Intergovernmental Panel on Climate Change (IPCC, 2013), anthropogenic emissions of greenhouse gases¹ have reached the highest level in history, and it is highly likely that human influence was the dominant cause of global warming observed since the mid-20th century. Intending to keep global warming below 2°C, even further to 1.5°C, governments signed the Paris Agreement in 2015, and IPCC was invited to prepare a report on the warming of 1.5°C. (IPCC,2018). The report (IPCC,2018) highlights that limiting warming to 1.5°C instead of 2°C has obvious benefits and is possible within the laws of chemistry and physics, but it will require “unprecedented” transitions in all aspects of society, and one of the immediate transitions is the energy transition.

This energy transition is not merely a replacement of an energy source (fossil fuels) with another energy source (renewable energy) (Juwet & Ryckewaert, 2018). Here “Transition” represents a chaotic and non-linear change (Verbong & Loorbach, 2012). It requires rethinking the entire energy system with all the related interactions and uses (IRENA, 2016).

Today, over half of the people live in urban areas, and this rate is foreseen to reach almost 70% by 2050 (United Nations, 2018). Although cities cover only 3 % of the earth, they are responsible for 75% of CO₂ emissions and almost two-thirds of global energy consumption. (United Nations, 2019). Cities are different from each other their energy needs and use due to its geography and climate, socioeconomic

¹ “Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth’s surface, the atmosphere itself and by clouds. This property causes the greenhouse effect. Water vapor (H₂O), carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄) and ozone (O₃) are the primary GHGs in the Earth’s atmosphere.” (IPCC Glossary, 2018).

characteristics, economy, and urban planning (Grubler et al., 2012; REN21, 2019a). However, they are the same in dependency on fossil fuels, so they are vulnerable to energy shortages and energy price fluctuations (ICLEI/UN-HABITAT/UNEP, 2009).

Today, almost 80 percent of global energy demand is met with fossil fuels (REN21, 2019b). Since the Industrial Revolution began, the atmospheric CO₂ concentration has increased by more than a third, and burning fossil fuels are the main reason for this increase (NASA, 2019). Since urban areas are the primary energy consumers, they are also the places where the energy problem culminates. Hence, there is a need for an action to avoid catastrophic climate change while maintaining a healthy living environment (IRENA, 2016).

1.2.2 Why Future Buildings Have a Crucial Role in Energy Transition?

Globally, the building stocks constituted the largest share of both final energy use (36%), and energy-related CO₂ emissions (39%), and these ratios are showing an increase due to population increase and floor area. (GlobalABC / IEA / UNEP, 2019). The building sector currently covers a residential and commercial floor area of 150 billion square meters (m²), and this is projected to increase by 80 % (to 270 billion m²) by 2050 (IRENA, 2018).

Inefficiently designed buildings may cause trouble in the future not only in terms of the environment but also in economics since their renovation may require high amounts of funds. (IRENA, 2016). Even with almost doubling global floor areas, the building sector's energy use can be reduced by nearly 30% to 2050 (IEA, 2019). Future efficiently designed buildings may make an important contribution to this reduction by reducing their energy demand and increasing their renewable energy generation potential (IRENA, 2016; GlobalABC/IEA/UNEP, 2020; IRENA, 2018).

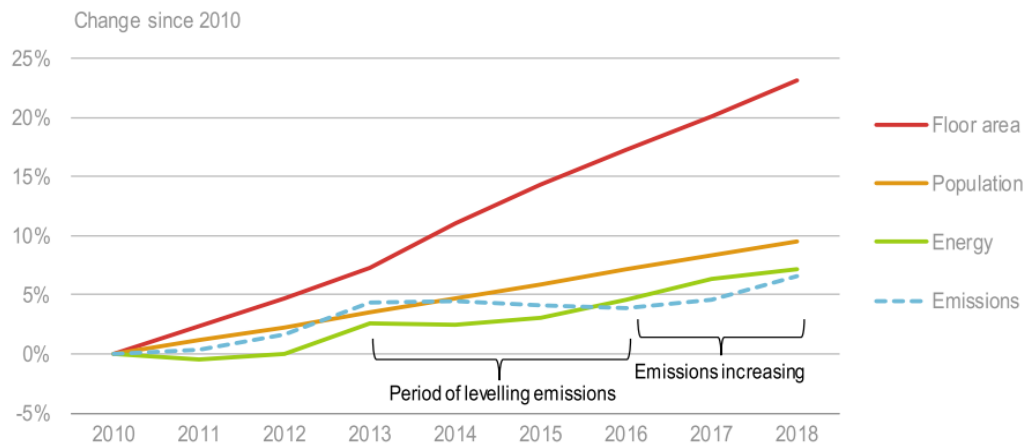


Figure 1.1. Changes in the building sector between 2010-18. (Source: GlobalABC / IEA / UNEP, 2019)

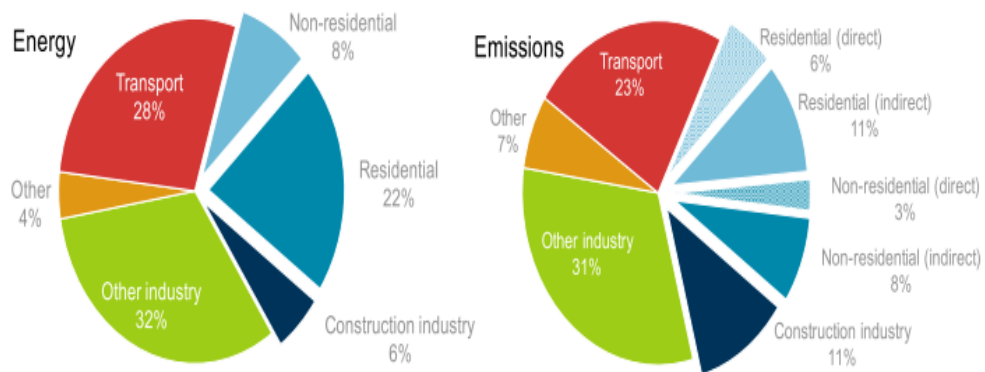


Figure 1.2. Global share of final energy and emissions in 2018 by sectors (Source: GlobalABC / IEA / UNEP, 2019)

1.2.3 What is the Role of Urban Designers in Energy Transition?

“The complex system of a city represents an ultimate cross section and cannot be adequately described through individual scientific disciplines. To achieve energy goals an interdisciplinary approach and integrated strategies -which consider the

technological developments as well as the social and economic relationships are needed” (URBEM-DK, 2016).

So, what is the role of urban designers in this holistic and interdisciplinary approach? In other words, how can urban designers contribute to the energy transition?

Although spatial planning confronted the energy problem with the 1973 oil crisis², the human-energy issue is not new. Since ancient times, human beings have sought ways to use the natural environment to improve their living conditions, and they almost instinctively created settlements by taking advantage of these natural mechanisms (Owens, 1986; Ionescu et al., 2015). (See for example: Steadman, 1975 and Ionescu et al., 2015). With the Industrial Revolution, which is often thought to be linked with the shift from organic to fossil fuels as an energy source (Unger, 2013), the new phase of human civilization has begun (Peker, 2005). Furthermore, during the twentieth century, energy worked in the urbanization process as a “permitting factor” that gives the direction of urban development (Owens, 1986).

The energy availability has increased continuously after the Second World War and built environments have been established on the assumption of uninterrupted. and low-cost energy. (Owens, 1986). With the oil crisis, it has been revealed that energy was not in unlimited availability, and urban areas were vulnerable in terms of energy. As a result, how energy could be included in planning has begun to be considered (Owens, 1986; Páez, 2010). Towards the mid-1980s, due to falling oil prices and finding new oil reserves, the energy problem seemed to be ignored (Páez, 2010). However, immediately after the rise of issues such as the increase of sustainability

² “Between October 1973 and January 1974, world oil prices quadrupled. By putting an end to decades of cheap energy, the 1973-74 oil crisis, which was led by Arab members of the Organization of Petroleum Exporting Countries (OPEC), exacerbated the economic difficulties facing many industrialized nations, forced developing countries to finance their energy imports through foreign borrowing, and generated large surpluses for oil-exporters.” (The Bankcoft Library, Berkeley, 2011)

and sustainable development ³ concerns of the late 1980s- the early 1990s witnessed the return of the energy problem as the main component of the agenda (Peker, 2005; Páez, 2010). Unlike the energy crisis of the 1970s, the energy problem is at the forefront this time with its environmental dimension (Peker, 2005).

Since the 1970s the links between energy and land use, urban form, mobility, urban growth, local climatic conditions have been discussed (see: Real Estate Research Corporation, 1974; Knowles, 1974; Steadman, 1975; Van Til, 1979; Oke, 1973; Oke, 1981; Owens & Rickaby, 1983; Owens, 1986; Owens, 1992; Newman & Kenworthy, 1999; Kenworthy et al., 1999; Newman & Kenworthy 2015) and have been shown how the proper planning may contribute to the solution of the energy problem. However, urban planning practices tend to deal with energy issues and the planning process separately. This situation causes an increase in the number of energy strategies, policies, and actions, which often deal with only a single aspect of the problem in case-by-case scenarios. These increases result in a complexity in the management of the two-way energy-planning relationships.

Considering the urban planning's influence and power on land use, mobility systems, and infrastructure, urban comfort, it would be more productive to rethink urban planning as a strategic tool rather than an agent, giving way to an increase in the number of strategies (De Pascali & Bagaini, 2019).

In this study, urban design is expressed as “creating a vision for an area and then deploying the skills and resources to realize that vision” (Llewelyn Davies Yeang,

³ Discussions on sustainability became popular after the 1987 Brundtland Commission and sustainable development was defined as follows: “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). “Sustainable development is a complex and contested concept that is often spoken about in terms of achieving an appropriate balance between three ‘pillars’ – the environment, economy, and society. Basically, it is about reorienting the development trajectory so that genuine societal advance can be sustained like other political concepts – such as ‘liberty,’ ‘democracy,’ and ‘justice’ – it helps to frame and focus debate while being open to constant interrogation and reinterpretation.” (Meadowcroft, 2007)

2009). The “vision” in itself brings the ability to think about or plan the future. Allen describes infrastructure as something that “prepares the ground for future building and creates the conditions for future events” (Allen,1999). Starting from this point of view, evaluating design as an infrastructure of tomorrow, and approaching the design itself as a strategy would be more efficient in the long term in terms of the energy transition. To make urban design as a strategic tool in the energy transition, it is needed to understand the effects of design decisions better as a first step.

1.2.4 Is It Possible to Make Informed Design Decisions Without Considering Interactions?

Both Energy and UHI considerations are complicated planning problem for urban areas. For solving complex planning problems, “it makes no sense to search for answers (or even to gather large amounts of data) before a question has been clearly formulated” (Schönwandt, 2019)

Making informed decisions in a complex environment, such as a city, is challenging. It requires understanding the “side-effects” of decisions on the whole system, and it requires understanding the impact of the different decisions on each other (Ouhajjou, 2016).

Therefore, before putting the research questions, there is a need to take into consideration some interactions:

1.2.4.1 Interactions Between Energy Supply Potential and Energy Demand

From the traditional design point of view, buildings have always been considered energy consumers (Kanters & Wall, 2014). However, in the 21st century planning the new urban environments requires a focus not only on the design of energy-efficient buildings but also on an energy-generating built environment (Wall et al.,

2017). With the integration of renewable energy into the built environment, consumers can also be producers at the same time (IRENA, 2016).

In this regard, it becomes crucial to provide proper decisions during the design process, mainly when solar access affects energy use and possible energy production (Kanters & Wall, 2014). For example, while increasing the window to wall ratio decreases the need for artificial lighting needs by increasing the daylight level, it increases the cooling requirement, and it restricts possible solar energy production due to the decrease of the façade area. On the other hand, the need for cooling in buildings in residential areas with higher density and where the smaller distance between buildings will decrease, but in this case, daylight utilization and possible PV energy production will decrease (Naboni et al., 2019; Natanian, Aleksandrowicz, et al., 2019a)

For this reason, tradeoffs between energy demand and supply is one of the critical reference points to be considered in the urban design process (Kanters & Wall, 2014; Naboni et al., 2019; Natanian, Aleksandrowicz, et al., 2019a; Wall et al., 2017)

1.2.4.2 Interactions Between Energy Demand and UHI Effect

Urban areas have higher air temperatures than the surrounding rural areas, and this phenomenon is called the urban heat island (Oke, 1995).

It means that buildings in an urban context are exposed to higher ambient temperature due to UHI effects compared to standalone buildings (Dorer et al., 2013). Thus, the UHI effect can have impacts on energy demand of buildings by increasing space cooling needs (Santamouris & Asimakopoulos 2001; Gorsevski et al., 1998; Kolokotroni et al., 2006) and decreasing space heating needs (Li et al., 2019).

Therefore, interactions between UHI effect and energy demand are worth considering in the urban design process (Bueno et al., 2013).

1.3 Research Questions

As described above, this research addresses understanding the effects of early design decisions on future urban residential areas' energy demand, energy supply potential and microclimatic conditions. In the background part, the significance of the research is explained, and to be able to consider the "side-effects," some interactions are briefly explored. In light of this, the following research questions are defined:

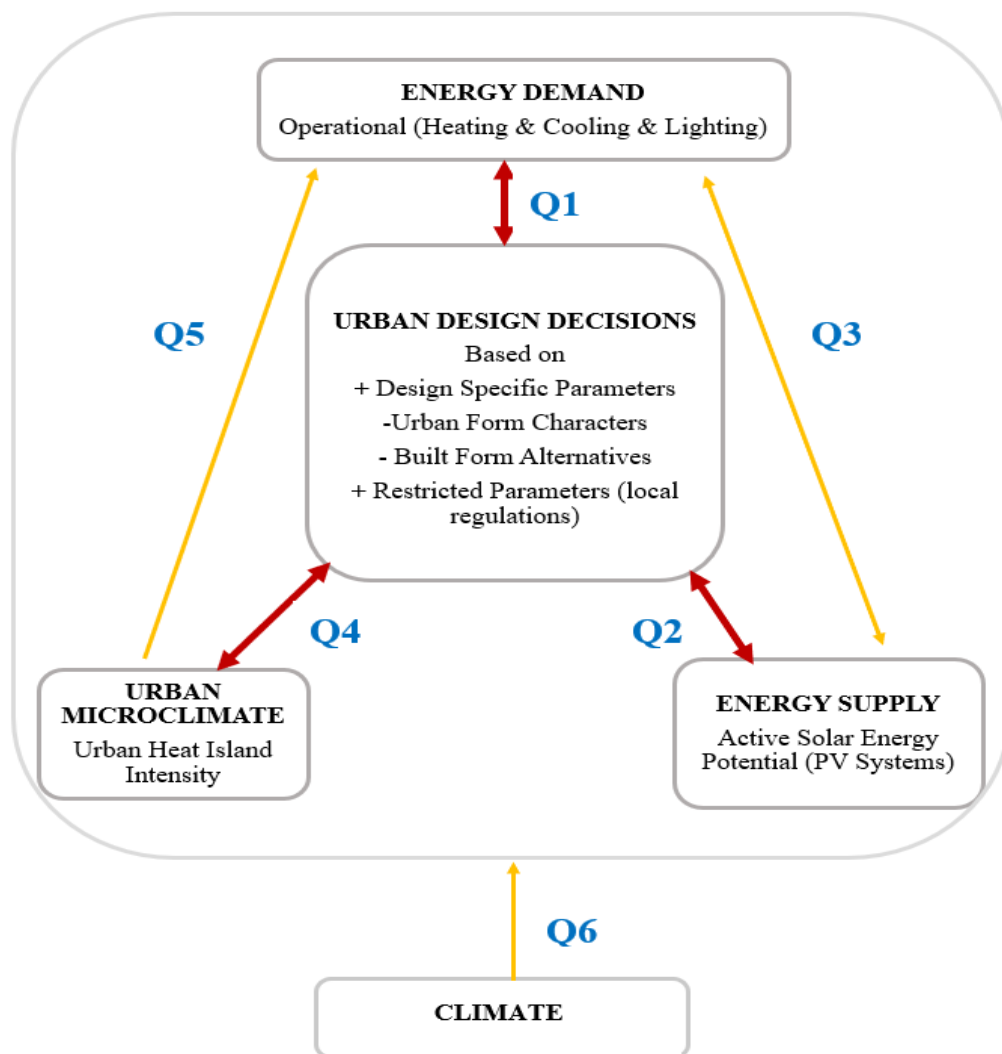


Figure 1.3. Schematic version of the research questions

Q1: How early decisions regarding the urban form at the block level affect the future residential buildings' operational (cooling, heating, lighting) energy demand?

Q2: How early decisions regarding the urban form at the block level affect the future residential buildings' active (PV Systems) solar energy potential?

Q3: How early decisions regarding the urban form at the block level affect the trade-offs between the buildings' energy demand and solar energy potential?

Q4: How early decisions regarding the urban form at the block level affect the future residential buildings areas' UHI intensity?

Q5: How UHI affect the buildings' cooling and heating energy demand?

Q6: How climate affect energy demand, solar energy potential, and UHI intensity?

1.4 Research Aim and Goals

The main focus of this research is to examine the impact of early phase urban design decisions, particularly those that are related to urban form, on energy demand, supply and UHI intensity in residential areas. This research aims to be a step toward integrating energy and urban microclimate considerations into the urban design process to help energy transition.

The study is carried out through simulations, and the specific goals are listed as follows:

- Determining the design parameters and performance metrics and simulation tools based on the literature review
- Composing a workflow based on the previous studies that provide evaluating the defined research questions
- Testing the workflow through three cases, which has different climate classes, in Turkey and preparing highlights which gained through tests results and discussions

1.5 Thesis Structure

This thesis has five chapters. The second chapter reviews climate change research, energy-related research, and urban heat island research in urban planning/ design literature and consists of three main parts: First part examines the recent research focuses and research directions. The second part examines the aspects of energy performance in urban design to specify the evaluation metrics and indicators. Finally, the third part focuses on the evaluation approaches and tools.

The third chapter presents the methodological framework of the study. “How this study is handled” is explained in detail. The research is performed through simulations in the Grasshopper environment and requires a workflow that combines different plug-ins. Therefore, this chapter begins with explaining workflow, which is adapted from previous studies and enables the answer to research questions. It ends with the selection of design parameters, performance metrics.

The fourth chapter presents the simulation results and discusses the research questions based on the simulation findings.

The conclusion chapter includes highlights of the findings and limitations of the study.

CHAPTER 2

LITERATURE REVIEW

This chapter examines research in energy studies relating to climate change mitigation and adaptation in urban planning/ design literature and aims to provide a reference point for the study's methodological framework. Rather than a chronologic approach, here, the goal is to present a review with a thematic approach.

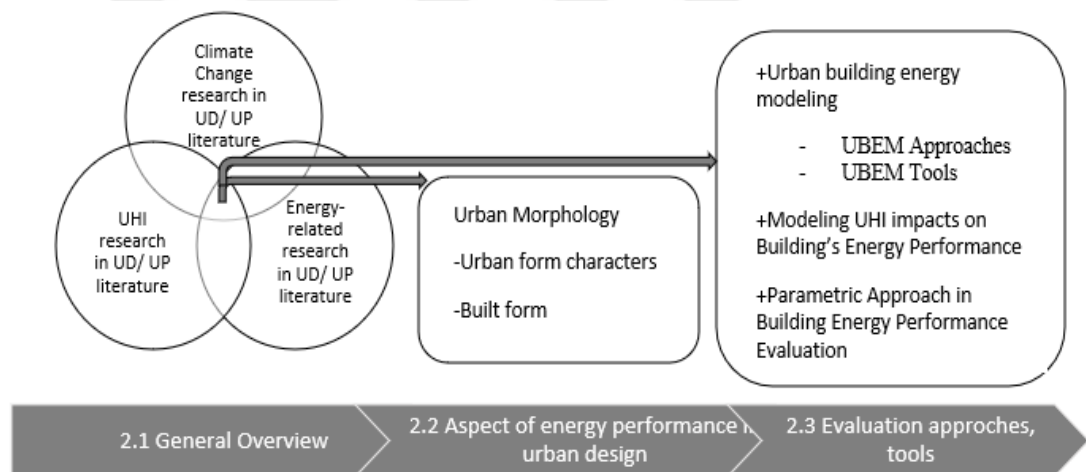


Figure 2.1. Schematic Version of the Literature Review Structure

This chapter consists of three main parts. The first part points out general trends and mainstream research directions of the related literature. The second part focuses on aspects of energy performance in urban design to specify the evaluation metrics and indicators. The third part reviews the urban building energy modeling approaches and tools.

As a first step, reviews were searched in Web of Science and Scopus databases using these keywords: “Urban Energy Transition,” “Urban Energy Demand,” “Urban Energy Supply,” “Urban Energy Systems,” “Urban Solar Energy Potential,” “Urban Heat Island,” “Climate Change.” The keywords were searched in the abstracts, titles, and keywords of the publications. As a second step, the collected 121 relevant review papers were reexamined considering the scope of the study and selected reviews were categorized in two groups: in the first group there are those which are used to point out general trends and mainstream research directions of the related literature (Table 2.1) where in the second group the papers will be used to point out research approaches, evaluation methods and tools in section 2.3 (Table 2.3, p.65)

2.1 General Overview

Three following question is answered to point out recent research trends and research directions:

- How the Urban Planning/Design Literature Has Addressed Climate Change?
- How the Urban Planning/Design Literature Has Addressed UHI studies?
- How the Urban Planning/Design Literature Has Addressed Energy studies to Climate Change Mitigation and Adaptation?

Table 2.1 Selected Reviews to Overview the Related Literature

Reference	Focus of the Review
(Aghamolaei et al., 2018)	Intermediate scale energy performance analysis
(Aleksandrowicz et al., 2017)	Research trends on UHI mitigation
(Amaral et al., 2018)	Principles of intermediate scale applications of the zero-energy concept
(Creutzig et al., 2016)	Demand-side solutions for climate change mitigation
(Dhar & Khirfan, 2017)	Climate change adaptation research

Table 2.1 (Continued)

(Gago et al., 2013)	Research on UHI and strategies for UHI mitigation
(Jiang et al., 2017)	Climate change research focuses and directions
(Kang et al., 2020)	Current research on energy systems for climate change mitigation.
(Santamouris, 2020)	Current research on urban overheating (climate change+ UHI) and its affects in urban areas
(Santamouris et al., 2015)	The ambient temperature increase's impact on electricity use.
(A. Sharifi, 2020)	Co-benefits and synergies between urban climate change mitigation and adaptation measures
(Ayyoob Sharifi, 2020)	Review of trade-offs and conflicts between urban climate change mitigation and adaptation measures
(Soares et al., 2017)	Energy and environmental performance of buildings
(Wang et al., 2019)	Urban energy performance evaluation
(Wu & Ren, 2019)	Research trends in UHI studies
(X. Zhang et al., 2018)	Intermediate scale urban energy systems/ renewable energy integration

2.1.1 How the Urban Planning Literature Has Addressed Climate Change?

Jiang et al. reviewed the urban planning and climate change research between 1990-2016 to determine its current research focuses and the development trends (Jiang et al., 2017). Similarly, focusing on climate adaptation⁴ studies, Dhar and Khirfan reviewed research from 2000 to 2013 on the leading urban planning and design journals to identify future research directions (Dhar & Khirfan, 2017). Since focusing on both adaptation and mitigation⁵ is essential for addressing climate change impacts, Sharifi analyzed the interactions between adaptation-mitigation

⁴ “the process of adjustment to actual or expected climate and its effects” (IPCC, 2014).

⁵ “a human intervention to reduce the sources or enhance the sinks of greenhouse gases” (IPCC, 2014).

measures in two reviews (A. Sharifi, 2020); Ayyoob Sharifi, 2020). The first paper explored the possible co-benefits and synergies; the second paper explored possible trade-offs and conflicts between adaptation and mitigation measures.

The findings of these reviews reveal that:

- i. As shown in Figure 2.2, after 2007, the amount of climate change studies increased abruptly (Jiang et al., 2017). In 2007 the fourth assessment report (IPCC, ARR4) had published and received Nobel Peace Prize in the same year. The report indicated the importance of climate change research at the city level and “may have contributed to successfully establishing climate change as a research challenge in the planning discourse” (Dhar & Khirfan, 2017; Jiang et al., 2017).

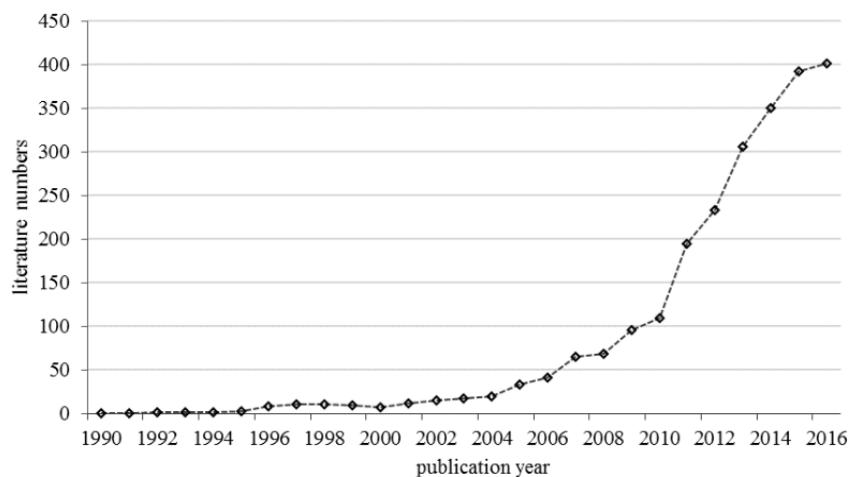


Figure 2.2. Studies focused on climate change in the urban planning literature between 1990 and 2016 (Jiang et al., 2017)

- ii. The current research focus of urban planning literature on climate change has fifteen themes under the four groups established according to the planning process (Jiang et al., 2017).

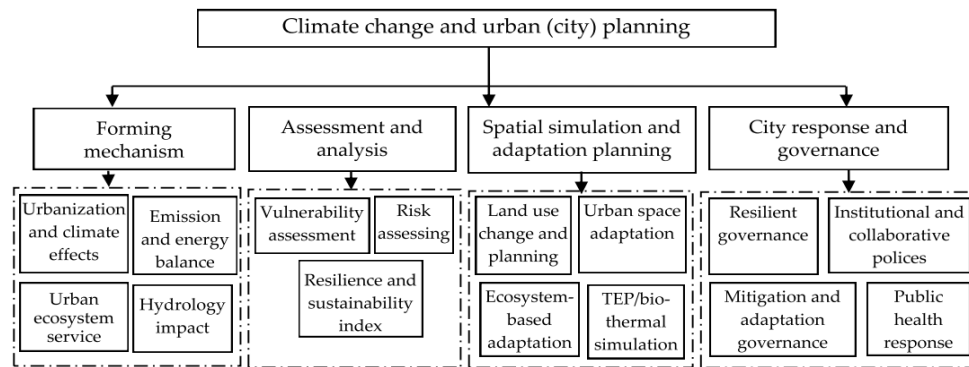


Figure 2.3. Current research focuses on urban planning for climate change (Jiang et al., 2017))

- iii. In general, the planning literature addressed climate change mitigation and adaptation separately. As it seen in Figure 2.4, most of the studies focus on climate change mitigation rather than adaptation. The figure also indicates a remarkable increase in adaptation studies. This increase can be explained by the hurricane Katrina that hit New Orleans in 2006 (Dhar & Khirfan, 2017).

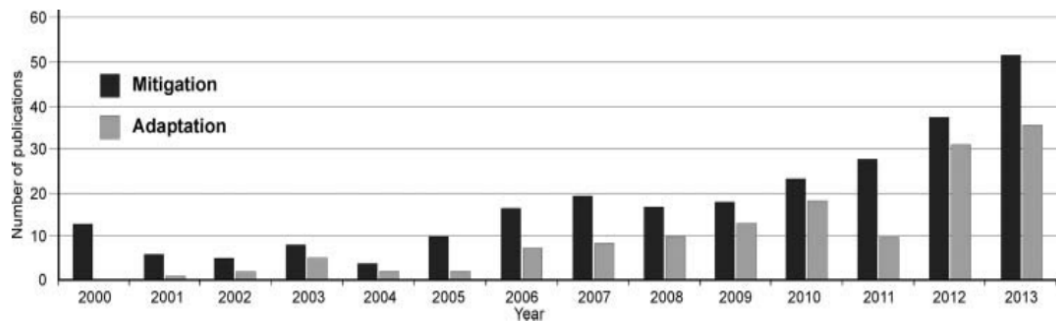


Figure 2.4. Comparison of the number of studies focused on climate change mitigation and adaptation in the planning literature (Dhar & Khirfan, 2017)

- iv. In planning/ design literature, climate change adaptation studies show mainly two tendencies. First, most of the studies focus on policies and conclude with normative policy guidelines; that means adaptation research rarely includes adaptation actions. Second, comparing transportation, infrastructure, and land use research, research focusing on the built environment design is less covered. Notably, there is a lack of urban design research at the neighborhood or district scale (Dhar & Khirfan, 2017).
- v. There is a growing interest in focusing on adaptation and mitigation measures together since both measures' equal importance is recognized. The number of studies analyzing the interaction between adaptation and mitigation measures also increases since they may have co-benefits, synergies, conflicts, and trade-offs. In general, building, transportation, energy, and waste categories' measures mainly target climate change mitigation- dealing with reducing the greenhouse gas emissions; green infrastructure, urban planning, and water categories' measures mainly target climate change adaptation- dealing with flooding, extreme temperature events, and droughts (Ayyoob Sharifi, 2020).
- vi. There is more comprehensive literature about the co-benefits between adaptation and mitigation measures than about their synergy. Reviewed papers show that although the main target of building, transport, energy, and waste sectors' measures is mitigation- the underlying reason for this can be explained by the fact that efficiency improvements in these sectors provide significant energy savings- they also provide essential co-benefits. For example, appropriate density levels, energy efficiency in buildings, distributed and decentralized energy systems are some of the measures that have higher potentials for co-benefits (A. Sharifi, 2020)
- vii. In literature, conflicts between adaptation and mitigation measures have been little explored. Trade-offs between adaptation and mitigation measures have been more explored comparing conflict studies. The findings reveal that energy and buildings are some of the leading sectors that may comprise trade-

offs. For example, attempting to control the greenhouse gas emission level may increase urban heat island intensity, thus adversely affecting health. Likewise, adaptation measures may cause reducing energy efficiency and increasing energy demand, which results in higher levels of greenhouse gas emissions (A. Sharifi, 2020).

2.1.2 How the Urban Planning/Design Literature Has Addressed UHI studies?

Although the UHI phenomenon has been known since the beginning of the 19th century, this phenomenon has been researched systematically after World War Two, following the increasing urbanization rates in western countries. Especially in the last three decades, UHI widely studied due to growing interest in examining urbanization's impact on the environment and society (Wu & Ren, 2019).

Wu and Ren reviewed UHI- related research broadly from 1990 to 2017 to not only identify the current research trends but also by dividing these studies into three time periods (1990-2000; 2000-2010; 2010-2017) examine the evolution and development of UHI-related research (Wu & Ren, 2019). They also included future directions of UHI research. Aleksandrowicz et al. focused on UHI mitigation efforts. Examining UHI mitigation studies between 2009 and 2013, they identified mitigation measures widely studied in literature and analyzed research trends (Aleksandrowicz et al., 2017). Gago et al. aimed to help decision-makers who have responsibilities in the planning process's design phase. They reviewed UHI literature on mitigation measures and suggested some UHI mitigation strategies. The study's discussion framework was driven by how urban morphology impacts local climate and how urban design may reduce energy consumption and carbon dioxide emissions (Gago et al., 2013). Santamouris et al. searched about urban overheating, which results from the combination of the urban heat island and global warming. They aimed to investigate the impact of urban overheating on the buildings' electricity consumption by comparatively reviewing past studies (Santamouris et al., 2015). Later on, Santamouris reviewed recent progress on urban overheating research. He

comprehensively examined the impact of urban overheating on energy, peak electricity demand, vulnerability, health, and pollutants concentration. Besides, he analyzed the synergies between UHI and heat waves (Santamouris, 2020).

These reviews reveal that:

- i. Until the last decade, studies on UHI have generally been considered from a meteorological perspective. As such, UHI studies have been predominantly published in meteorology journals. In the last decade, studies on environmental science have attracted great attention, and the UHI research focus shifted from theoretical to more applied research associated with urban planning and design. In other words, finding solutions to UHI-related problems gained more priority comparing to understanding and quantifying the UHI. Building and construction technology-related journals have become popular journals from the point of UHI-related research papers. This popularism is consistent with the researcher's tendency in recent years to perform comparatively smaller spatial-scale studies while analyzing thermal issues in cities (Wu & Ren, 2019).
- ii. According to Wu and Ren's keyword analysis results, examining and quantifying the impacts of UHI on public health seems one of the research directions for UHI research. Secondly, as a result of increasing extreme heat events, heat wave studies are also seen as an emerging direction for UHI research. Lastly, mitigation and adaptation strategies remain an important research direction in the future as well as now (Wu & Ren, 2019).
- iii. In the design phases of the urban planning process, there is the possibility of implementing several strategies for UHI mitigation since how the buildings and urban structures are distributed in urban areas affects the UHI formation. The reason behind that lies in that the this distribution affects the amount of solar exposure and airflows (Gago et al., 2013).

- iv. Using two different classification systems, both figure 2.5 and figure 2.6 summarize the commonly studied mitigation efforts in the literature. Gago et al. identified planning strategies for UHI mitigation in two major categories. The first category includes cityscape elements; parks and green areas, trees and vegetation, green roofs, albedo, pavements, while the second category, under the title of urban design, discusses the effects of design on solar radiation and airflow (Gago et al., 2013). Aleksandrowicz et al. identified eleven mitigation measures and classified them under the four major intervention categories, which reflect policymakers' common perspective: building envelope, urban landscaping, pavements, and street geometry (Aleksandrowicz et al., 2017).
- v. Generally, researchers tend to focus on a single mitigation measure rather than focusing on several measures. Among the mitigation measures, some (e.g., shade trees, cool building envelopes, ground vegetation, and green roofs) have been studied more than others (e.g., street geometry). It can be said that the ones that may readily implement through local urban planning regulations were studied more than others. Another reason may be that studies focusing on more easily implemented measures receive funding more easily (Aleksandrowicz et al., 2017).

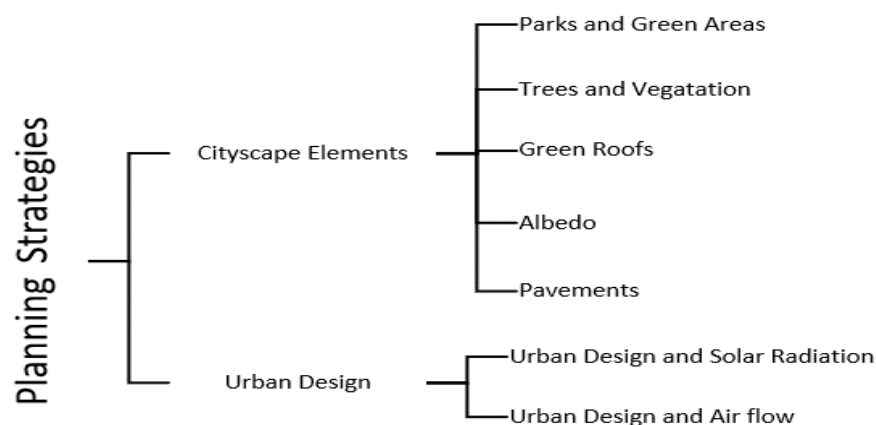


Figure 2.5. Planning strategies for the mitigation of the UHI (Gago et al., 2013)



Figure 2.6. Commonly studied UHI mitigation measures in the literature (Aleksandrowicz et al., 2017)

- vi. Energy demand and generation is one of the most affected sectors from urban overheating (Santamouris, 2020). Urban overheating, which results from global warming and urban heat island, causes intensification of buildings' cooling energy demands. On the other hand, an increase in ambient temperature may reduce the need for heating in climates where heating needs are predominant (Santamouris et al., 2015).
- vii. There are six main types of research in the literature that examine the impact of urban overheating on energy demand and generation (Figure 2.7) These studies mainly focus on the potential intensification of the cooling energy demand rather than the potential decrease in the buildings' heating demand (Santamouris, 2020).

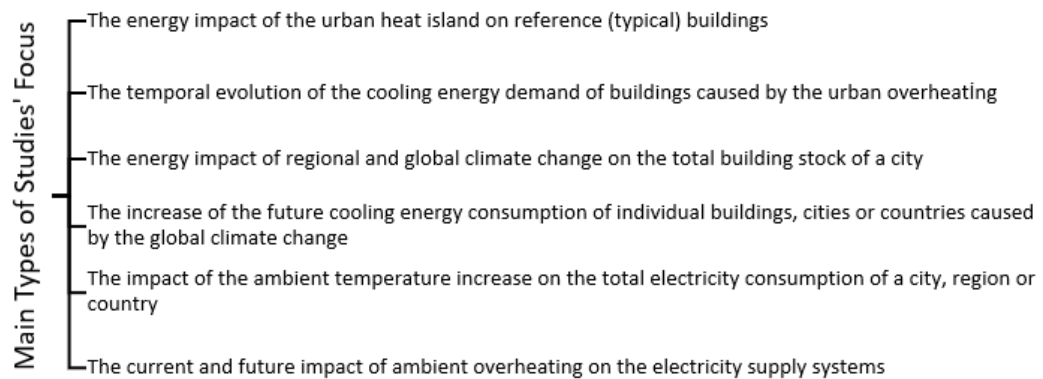


Figure 2.7. Main types of research examining the impact of urban overheating on energy demand and generation (Santamouris, 2020)

2.1.3 How the Urban Planning/Design Literature Has Addressed Energy studies to Climate Change Mitigation and Adaptation?

In the introduction chapter, why energy issues need to be considered in urban planning and design are explained and related to past studies. While explaining the role of urban planners and designers in energy transition, how energy issues are handled in literature is briefly mentioned with the chronological approach. Unlike the introduction part, here, selected reviews are analyzed to show the current research focuses. At the same time, this part aims to explain some recent, recurring concepts to provide a more profound understanding of the related literature.

Kang et al. reviewed more than one thousand articles published between 2015-2019, focusing on energy issues. They aimed to provide a systematic review of energy systems for climate change mitigation (Kang et al., 2020). Creutzig et al. focused on demand-side solutions in energy end-use sectors. Their review aimed to analyze the options in urban, building, transport, and agricultural sectors for climate change mitigation (Creutzig et al., 2016). X. Zhang et al. focused on supply-side solutions at cluster level. They reviewed urban energy system and aimed to analyze the challenges of implementing of renewable-energy-sources (RES) solutions to urban energy systems (X. Zhang et al., 2018).

Amaral et al. discussed performance aspects of the nearly zero-energy concept from an architectural/ urban planning perspective. They focused on the intermediate urban scale and aimed to understand better both challenges and consequences of applying this concept to the district scale (Amaral et al., 2018). Similarly, Aghamolaei et al. analyzed energy performance evaluation of the built environment at district/neighborhood scale. Their review suggested a framework to overcome the energy performance assessments' challenges in the early design phase (Aghamolaei et al., 2018). In their review, Soares et al. discussed ten research topics related to buildings' energy and environmental performance. The research topics include the entire life cycle of the buildings. Although the selected research topics' main common feature is to support the built environment's transition to a more sustainable one, the selected topics cover different scales (building, region, urban scale) and different assessment methods (Soares et al., 2017). Like the reviews mentioned above, Wang et al. also discussed urban energy performance. They provided a systematic review including current recent focuses, evaluation methods, indicators, and future research dynamics (Wang et al., 2019).

These reviews reveal that:

- i. There is a consistent growing research interest in energy studies for climate change mitigation in the available literature. In the studies conducted between 2015-2019, among the research topics, energy production receives the most significant interest, followed by studies dealing with the end-use of energy that means the researchers showed more interest in supply-side studies than demand-side studies (Kang et al., 2020).
- ii. According to Creutzig et al., there are two main reasons why demand-side studies attract less attention than supply-side studies. First, demand-side solutions are inherently less compatible with quantitative analysis and precise applications since these solutions often involve end-users that means demand-side solutions embedded in end users' lifestyle and behavioral change. On the contrary, technological solutions are generally more suitable for quantitative analysis and easier to apply to models. Second, unlike

supply-side solutions, demand-side solutions presuppose modified behaviors. For example, supply-side solutions assume that energy consumption preferences will continue to be like the current situation, while demand-side solutions assume a positive shift in preferences. That is, demand-side solutions contradict the revealed-preference approach in economics as they involve explicit normative positions (Creutzig et al., 2016).

- iii. There is increasing interest in studies that address the whole energy system rather than studies that deal with energy processes separately to examine the interactions between energy systems and climate change (Kang et al., 2020). In this regard, the intermediate scale plays a crucial role in energy studies since it is large enough to examine the trade-off between energy supply and demand better than stand-alone buildings and still small enough for a concrete analysis (X. Zhang et al., 2018).
- iv. On the other hand, when studying energy at the urban scale, it is essential to define the limits of the scale to develop appropriate evaluation methods. Clear boundary definitions have not yet been made in the current literature. Research that considers the interaction between buildings, the terms “block”, “district”, “neighborhood”, or “community” are used interchangeably (Amaral et al., 2018; Soares et al., 2017).
- v. In planning/design literature, energy performance (analysis/evaluation/assessments), zero energy (buildings/districts/neighborhoods) are some of the most recurring concepts in energy studies:

a) *Energy Performance Concept*

Energy efficiency is a generic term that refers to "using less energy to produce the same amount of services or useful output" (Patterson, 1996), and the energy performance concept relies on this term (Wang et al., 2019). Since quantifying energy efficiency must rely on a series of indicators (Patterson, 1996), and including economic output indicators is insufficient to represent

energy efficiency, the researchers have started using the energy performance concept (Wang et al., 2019).

The concept has taken part in many different disciplines with a wide range of research areas. It has been affected by many input-output variables, and its content has changed and expanded over time. It is used for analyzing micro to macro-scale areas, from regional energy performance to building energy performance. Within this transformation of the concept, energy well-being performance, carbon emissions performance, energy-saving and emissions reduction performance, and environmental performance emerged (Wang et al., 2019).

Urban energy performance is defined as "the level of producing optimal outputs based on energy and other inputs through urban development activities under the influences of certain social regulations and factors." Its analysis is based on vast data and information, and it is strictly linked to a city's economic, social, ecological, environmental, and well-being aspects (Wang et al., 2019). Fig 2.8 categorizes the studies related to urban energy performance in the available literature.

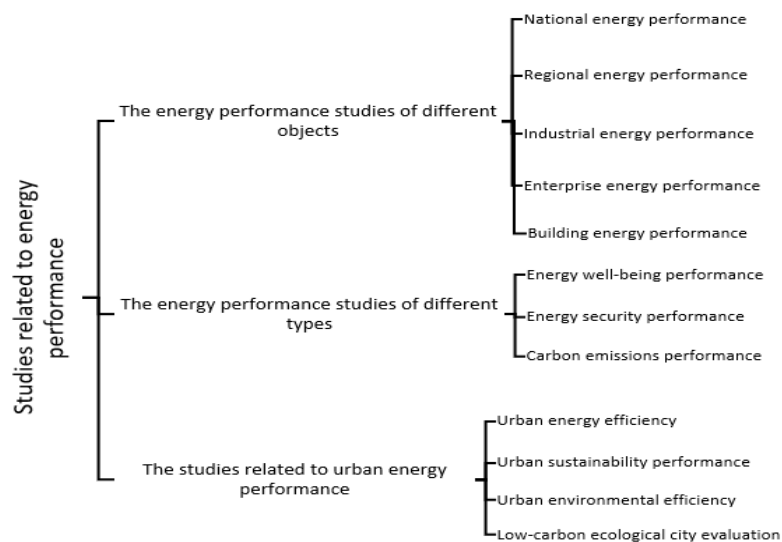


Figure 2.8. Studies related to urban energy performance in the available literature (Wang et al., 2019)

b) Zero Energy Concept

Zero energy is a widely used concept in energy performance evaluation studies in the built environment (Aghamolaei et al., 2018; Amaral et al., 2018; Soares et al., 2017). After the 20/20/20 climate change and energy targets (20% cut in greenhouse gas emissions (from 1990 levels); 20% of EU energy from renewables; 20% improvement in energy efficiency) were set, the EU made action plans in several areas to meet its targets (European Commission, 2020). In this regard, the Energy Performance of Buildings Directive (EPBD, 2010) was recast in 2010; the nearly zero-energy building concept (nZEB) aims to decrease energy demand while increasing the energy supply with the integration of renewables, has been introduced.

In this directive (EPBD-recast, 2010) nearly zero-energy building is defined as:

“... a building that has a very high energy performance where the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources, produced on-site or nearby.”

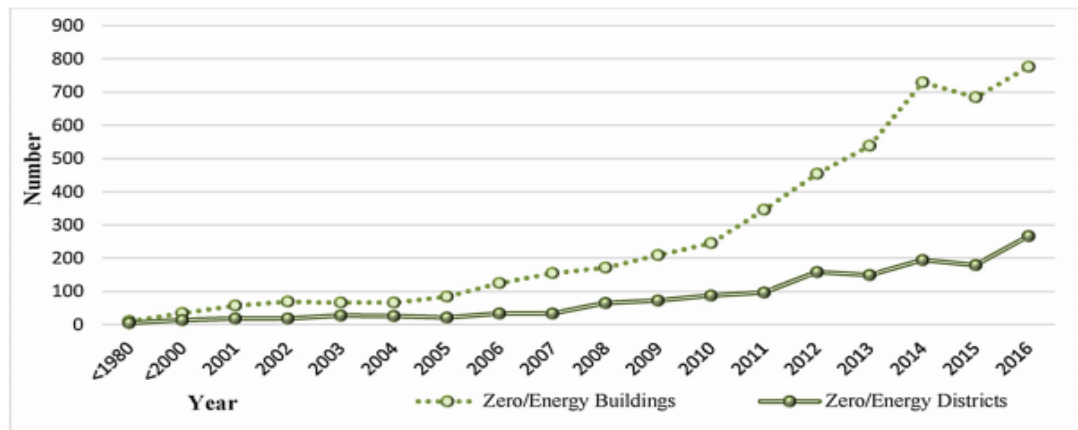


Figure 2.9. Distribution of studies focused on energy performance of buildings in the Scopus database by scale (Aghamolaei et al., 2018)

Undoubtedly, achieving nZEB goals are essential and unquestionable but considering the energy performance of buildings in the urban context is more complex than a stand-alone approach. The intermediate scale plays a crucial role since this scale allows to consider interactions between buildings (Aghamolaei et al., 2018; Amaral et al., 2018; Soares et al., 2017). Thus, there is a growing interest in studying energy performance on the intermediate scale. Figure 2.9 shows the number of studies published in energy-related subjects on the intermediate scale, while figure 2.10 categorizes these studies according to their primary objectives.

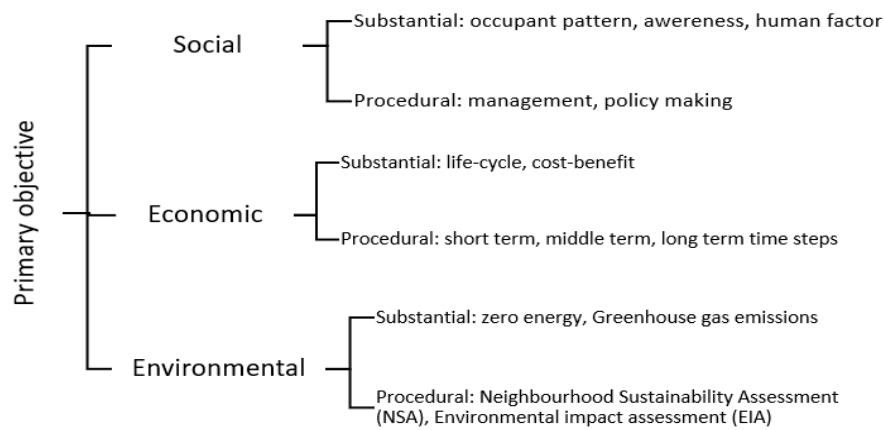


Figure 2.10. Classification of intermediate scale energy performance studies in existing literature according to their primary objectives (Aghamolaei et al., 2018)

- vi. As shown in figures 2.8 and 2.10, energy performance studies have a broad scope of research in the literature. At the same time, the boundaries of this research area tend to expand according to research purposes and research questions. Therefore, a common framework for evaluating energy performance does not exist in the literature. In energy performance studies, there is a need to specify the measurable features (energy performance metrics/indicators) following the research's perspective, purpose, and content (Aghamolaei et al., 2018; Amaral et al., 2018; Wang et al., 2019).

2.2 Aspects on Energy Performance in Urban Design

This part analyzes aspects of energy performance in urban design to specify the evaluation metrics and indicators, which is crucial for the study's methodology.

2.2.1 Urban Morphology

“Urban form as a term has been used to loosely signify different aspects of space’s configuration in cities along with its use and agents, and is therefore a polysemic term,” (Fleischmann et al., 2020), while in this study it refers solely to the physical form.

Urban morphology is “the study of urban form” (Cowan, 2005, as cited in Marshall & Çalışkan, 2011) and “about inferring urban form-function relationships” while “urban design is about expressing them” (Marshall & Çalışkan, 2011). As Buckminster Fuller declared more than 50 years ago, “[...] Forms are inherently visible and no longer can ‘form follow functions,’ because the significant functions are invisible.” What if the invisible functions were to provide energy balances and mitigate the urban heat island effect? How would urban design express them?

This study focuses on the effects of urban design decisions on the early design stage in future residential built environments on energy demand, energy generation potential, and urban heat island intensity. The focus of the study is not to provide optimization between these three criteria nor to create an ideal urban form. It is to create a discussion point for designing better quality-built environments in terms of energy balance and urban microclimate by better understanding the decision-effect mechanism. The aim is not to make visible the "invisible forces" that determine the main direction of the function but to take a step to ensure their invisible flow in equilibrium.

The relationship between urban morphology and urban design is established bilaterally through urban form attributes, built form alternatives, and design

decisions within the study framework. The following parts will examine urban form attributes that affect energy demand, supply and UHI intensity and built form alternatives.

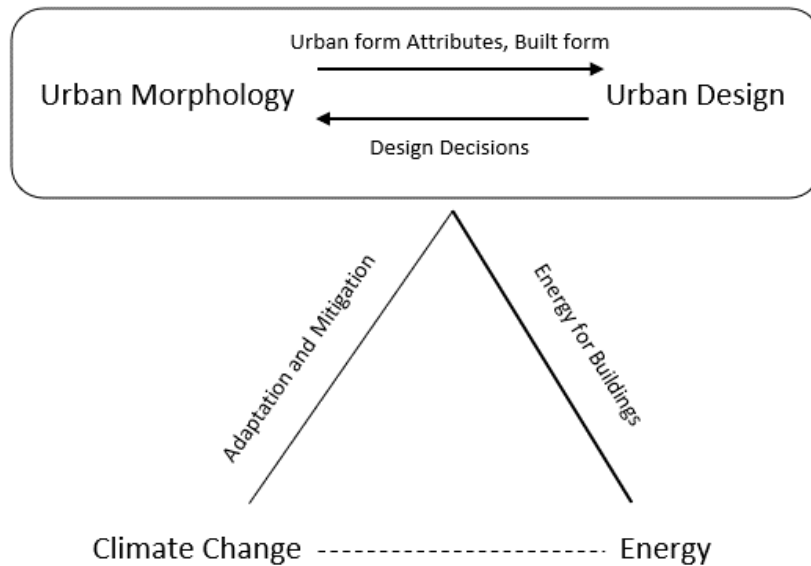


Figure 2.11. The Link Between Urban Morphology and Urban Design (Adapted from Oliveira, 2016 p.172)

2.2.1.1 Urban Form Attributes

“The relevance of the physical attributes to urban planning lies on the ability to thoroughly characterize and quantify them” (Silva et al., 2017). In this way, more objective and informed decisions can be made in the early urban design phase toward energy transition in cities. So, what are the urban form attributes that affect energy demand, supply, and UHI?

In research papers, "terms such as 'attribute,' 'variable,' 'measurement,' 'metric,' 'index,' 'character,' 'indicator' or 'proxy' are often used interchangeably in urban morphology to signify the measurable feature of an object" (Fleischmann et al.,

2020). Due to these discrepancies in terminology, obtaining an effective strategy for reaching relevant research papers was challenging.

The review by Silva et al. was selected as the starting point for this part (Silva et al., 2017). They discussed how the urban form attributes affect the energy demand. While examining the urban form attributes, they included both the built environment and the transportation sector. They categorized the built environment-related attributes as density, diversity, green areas, compactness, shading, passivity, and orientation. Then, they presented indicators and metrics which brought together from existing literature for these attributes.

Following the mentioned study, the same categorization is used in this part, and the attributes that affect the energy supply and the urban heat island were also examined. Since only the built environment was dealt with in this study, to abide by the study's aim, the studies focused on transportation were eliminated. The snowball technique was applied based on the mentioned review to reach the relevant studies and benefited from the reviews in the previous part.

Table 2.2 summarizes the urban form characters that affect energy demand, energy supply and, urban heat island intensity found in the existing literature.

Table 2.2 Urban form characters that affect energy demand, energy supply and, urban heat island intensity (Extended from (Silva et al., 2017))

Character	Indicator	Metric	Study Focus	Source
Density	1. Building height	Number of floors	UHI	(Aiko et al., 2015)
			Energy Demand	(Vartholomaos, 2017) (Ibrahim et al., 2021)
			Solar Energy Potential	(Sarralde et al., 2015) (Martins et al., 2016)
	2. Distance between buildings	Street width plus building setback distance	Energy Demand	(Ibrahim et al., 2021)
			Solar Energy Potential	(Sarralde et al., 2015) (Martins et al., 2016)
	3. Urban intensity	Population or jobs per land area	Energy Demand	(Newman & Kenworthy, 2006)
	4. Activity intensity	Population and jobs per land area	Energy Demand	(Newman & Kenworthy, 2006)
	5. Floor space index (FSI) or Floor area ratio (FAR) or Plot ratio	Gross floor area/total floor area	UHI	(Chokhachian et al., 2017) (Yin et al., 2018)

Table 2.2 (Continued)

			Energy demand	(Natanian, Aleksandrowicz, et al., 2019b)(Godoy-shimizu et al., 2021)
			Daylight	(Cheng et al., 2006)
			Solar energy potential	(Cheng et al., 2006; Kanters & Horvat, 2012b; Kanters & Wall, 2014; Martins et al., 2016; Mohajeri et al., 2016; Sarralde et al., 2015)
	6.Ground space index (GSI) or Site coverage	Building coverage area(footprint)/total ground area (%)	UHI	(Aiko et al., 2015; Yin et al., 2018)
			Energy demand	(Aiko et al., 2015; Godoy-shimizu et al., 2021; Mangan & Koçlar Oral, 2020; Yin et al., 2018)
			Daylight	(Cheng et al., 2006)

Table 2.2 (Continued)

			Solar energy potential	(Cheng et al., 2006; Martins et al., 2016; Mohajeri et al., 2016; Sarralde et al., 2015)
	6. Subdivision indicator	Number of parcels/ total ground area	Energy Demand	(Bourdic et al., 2012)
	7. Building (dwelling) unit density	Number of buildings/ total ground area	Solar energy potential	(Mohajeri et al., 2016)
	8. Open space ratio (OSR)	Non-built area/ total floor area	Energy demand	(Berghauser Pont & Haupt, 2007)
Diversity	1. Mixed use index	Total residential floor area/total ground area	Energy demand	(van den Hoek, 2008)
	2.Dissimilarity index	$\frac{(\sum_j^k \sum_l^8 \frac{X_l}{8})}{K}$	Energy demand	(Cervero & Kockelman, 1997)
	3.Entropy	$\frac{(\sum_k (\sum_j P_{jk} \ln(p_{jk}))/\ln(J))}{K}$	Energy demand	(Frank & Pivo, 1991)
	4.Structural objectivity	$\frac{1}{Cat} \sum_1^{cat} 1 - \frac{Current\ land\ distribution}{Targeted\ land\ distribution}$ <i>cat = # of land use category</i>	Energy demand	(Bourdic et al., 2012)

Table 2.2 (Continued)

Green Areas	1.Spatial distribution index	$\frac{Q}{Q-1} * (1 - \sum_{district=1}^Q (\frac{Green\ areas}{Total\ site\ area})^2)$ $Q = \# \text{ of districts}$	Energy demand	(Bourdic et al., 2012)
	2. Green coverage ratio	Total green areas/ total site area	UHI	(Fahmy & Sharples, 2009; Ng et al., 2012)
			Energy demand	(Ko & Radke, 2014)
	3. Green area geometry or mean shape index	Green area's perimeter/ total green area	Cooling effect	(Jaganmohan et al., 2016)
Compactness	1.Surface-to-volume ratio (SVT)	S/V (Total surface of buildings (façades and roofs)/ Total volume of the buildings)	Daylight	(Ratti et al., 2003; Taleghani et al., 2013)
			Energy demand	(Depecker et al., 2001; Ratti et al., 2005; Taleghani et al., 2013)
	2. Size factor	$V^{1/3}$ Length of the equivalent cube version of building(s) volume	Energy demand	(Bourdic et al., 2012)

Table 2.2 (Continued)

	3.Façade-to-site ratio	Total façade area/ site area	UHI	(Aiko et al., 2015; Bueno et al., 2013)
	4.Built compactness	$C_B = 4B / DP$ where; B = building footprint area D= diameter of the building, P= Perimeter of the building	Energy demand	(Marshall et al., 2010)
	5.Form factor	$S / V^{2/3}$	Energy demand	(Bourdic et al., 2012)
	6.Volume-area ratio	Total building volume/ total ground area	Solar energy potential	(Mohajeri et al., 2016)
Shading	1.Urban horizon angle (UHA)	Height of the opposite buildings / The canyon width: $H/W = \tan (UHA)$	Energy demand	(Ratti et al., 2005)
	2.Obstruction sky view (OSV)	$H/W = \cos (OSV)$	Energy demand	(Ratti et al., 2005)
	3.Sky view factor (SVF)	Visible sky ratio at a certain location	UHI	(Cheung et al., 2016; Yin et al., 2018)
			Solar energy potential	(Poon et al., 2020; J. Zhang, Xu, Shabunko, Tay, et al., 2019)

Table 2.2 (Continued)

	3.Aspect ratio	H/W (H: Height of the building; W: urban canyon width)	UHI	(Allegrini et al., 2012; Chokhachian et al., 2017; Theeuwes et al., 2014)
			Energy demand	(Ali-toudert, 2009; Allegrini et al., 2012; Evans et al., 2017; Hachem et al., 2013; Mangan & Koçlar Oral, 2020; Mckeen & Fung, 2014; Strømman-Andersen & Sattrup, 2011)
			Daylight	(Strømman-Andersen & Sattrup, 2011)
			Solar Energy potential	(Hachem et al., 2013; Martins et al., 2016)
Passivity	1.Passive/non passive ratio	Buildings' passive areas/ non passive areas	Energy demand	(Hachem et al., 2013; Martins et al., 2016; Ratti et al., 2005; Zhu et al., 2018)
	2.Plan depth	Volume/ exposed wall area	Energy demand	(Evans et al., 2017)

Table 2.2 (Continued)

Orientation	Orientation	Degree, radian	Energy demand	(Aksoy & Inalli, 2006; Hachem et al., 2013; Samuelson et al., 2016; Vartholomaios, 2017) (Ibrahim et al., 2021)
			Solar energy potential	(Ali-toudert, 2009; Hachem et al., 2013; Kanter & Horvat, 2012b; Kanter & Wall, 2014; Mangan & Koçlar Oral, 2020; Natanian, Aleksandrowicz, et al., 2019b)
			Daylight	(Samuelson et al., 2016)
			UHI	(Aleksandrowicz et al., 2017; Gago et al., 2013)

2.2.1.1.1 Density

Among the urban form attributes associated with energy, density is the most widely used (Silva et al., 2017), and many different definitions are available in the related literature. “In general terms, urban density describes the degree of concentration or compactness of people or development in a city.” (Hess, 2021). In other words, urban density description is based on “people concentration” or “built-area concentration”.

Researchers discussed urban density concept in many distinct perspectives in energy relevance, and they used several indicators to measure density. For example, Newman and Kenworthy used “urban intensity” which refer to population or jobs per urban area (Newman & Kenworthy, 1989), and in their later research they used “activity intensity” which refer to population and jobs per urban area (Newman & Kenworthy, 2006). Figure 2.12 shows how the peoples’ energy consumptions change with activity intensity in Melbourne, Australia while Figure 2.13 shows how the energy consumption change with urban intensity in the selected cities.



Figure 2.12. Energy consumption versus activity intensity in Melbourne, 2002 (Newman & Kenworthy, 2006)

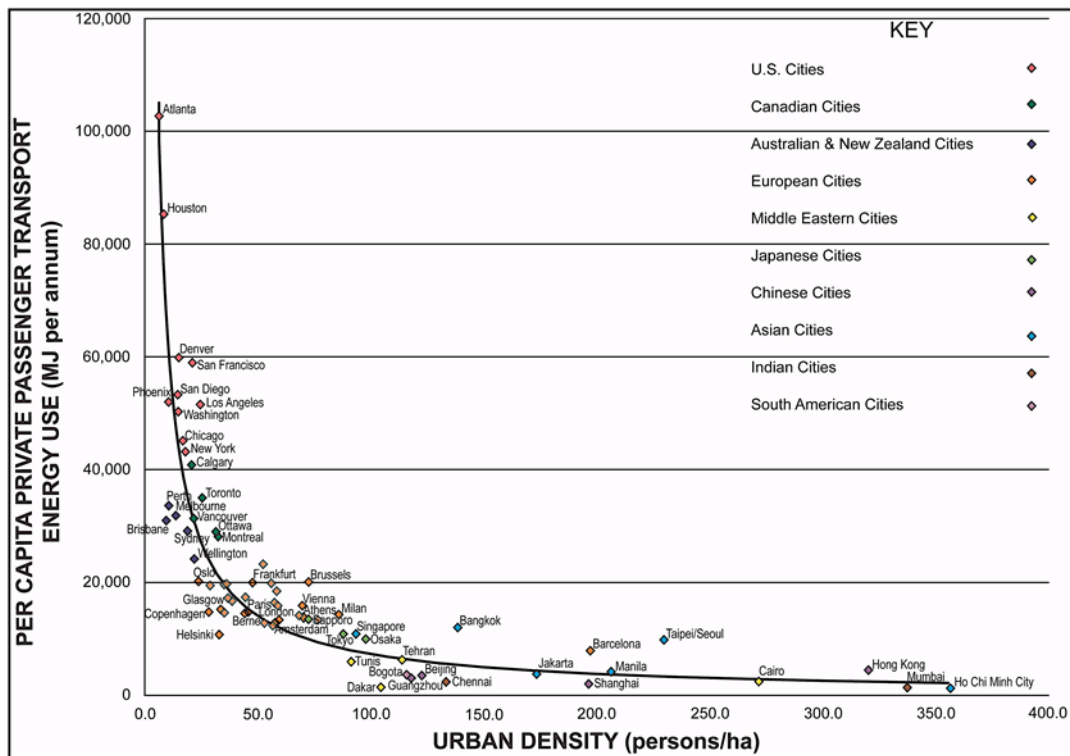


Figure 2.13. Energy consumption versus urban intensity in the selected cities (Kenworthy et al. 1999)

Their research findings reveal that the relationship between energy consumption for travel and urban density is significant. The higher the urban densities, the higher the energy savings. On the other hand, Bertaud drew attention to the importance of spatial organization and claimed that how the population is distributed to the city is also a key factor for energy consumption since the spatial distribution also affects the travel patterns. According to him, using average density (urban intensity) as an indicator alone is “crude” to express urban density since it does not consider how the population is spatially distributed (Bertaud, 2001).

Figure 2.14 shows how the population is spatially distributed in selected cities (The same scale and the same isometric view is used for representations).

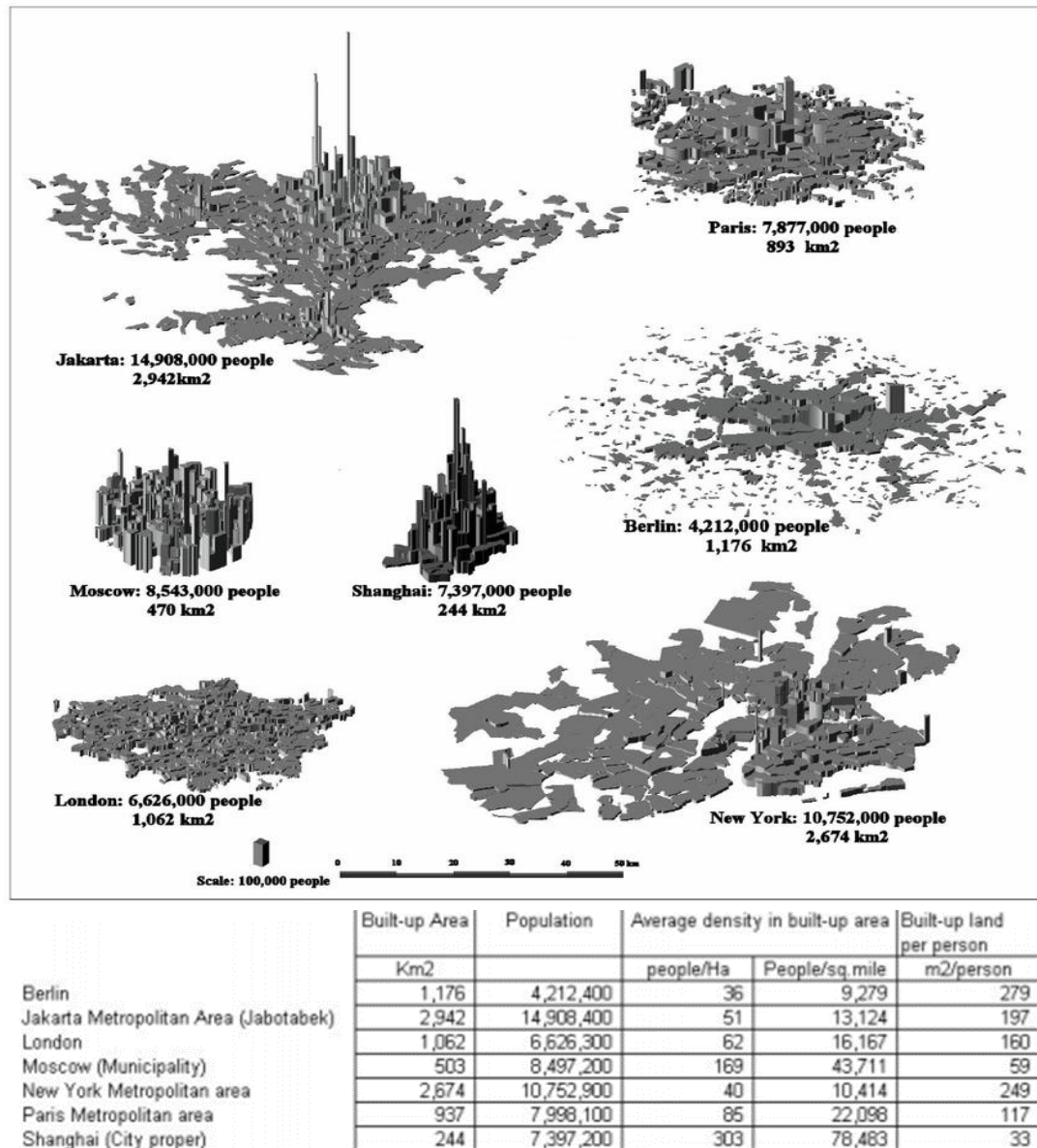


Figure 2.14. Spatial distribution of population in selected cities (Bertaud, 2001)

Similarly, considering the building density, using only the ratio of the number of buildings to the total area as a density indicator is again a "crude" representation. Because the same ratio can be achieved by different spatial configurations (Berghauser Pont & Haupt, 2007).

Here is an example of the distribution of the same number of dwelling units in the same area in different configurations:

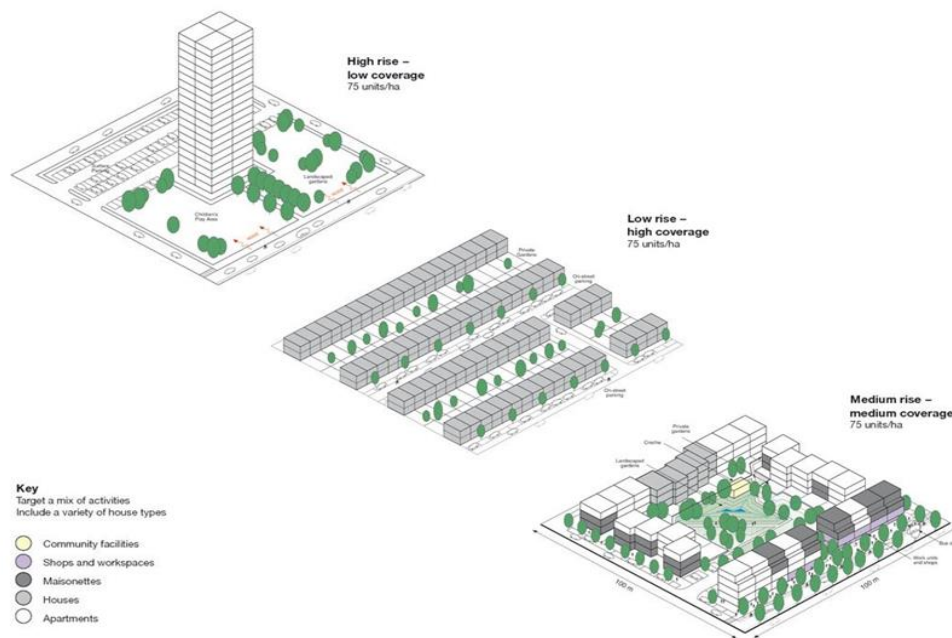


Figure 2.15. Different spatial configurations of 75 dwelling units in the same area (Urban Task Force, 2005, p.53)

Another widely used density indicator is floor area ratio (FAR) or floor space index (FSI) or plot ratio which is the ratio of buildings' gross floor area to total built area (Figure 2.18, top left). However, since this indicator is the ratio, it is possible to obtain the same ratio with buildings with high floors and small footprints or buildings with low floor ratios and large footprints (Figure 2.16) (Berghauser Pont & Haupt, 2007).

Therefore, it may be misleading to establish the relationship between urban form and density by using only one metric (Berghauser Pont & Haupt, 2007). To deal with this situation, the researchers used multiple indicators simultaneously to quantify the density. (e.g., site coverage, building height, aspect ratio).

For example, (Pont & Haupt, 2005) developed Spacemate Diagram, which combines floor area ratio, site coverage ratio and open space ratio and building height. Figure 2.17 shows how the three urban configurations in figure 2.16 are positioned in the diagram.



Figure 2.16. Three different urban configurations with same FAR (Berghauser Pont & Haupt, 2007)

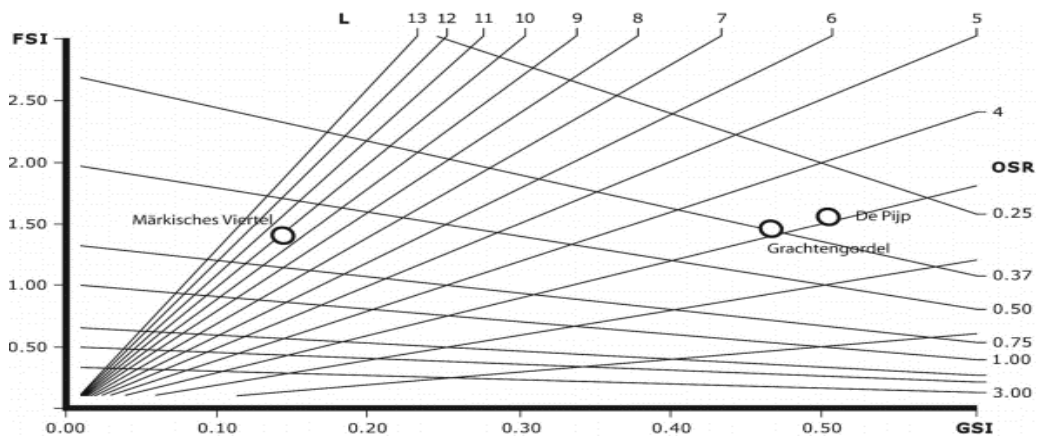


Figure 2.17. Same three urban layouts' positions in the Spacemate Diagram (Berghauser Pont & Haupt, 2007)

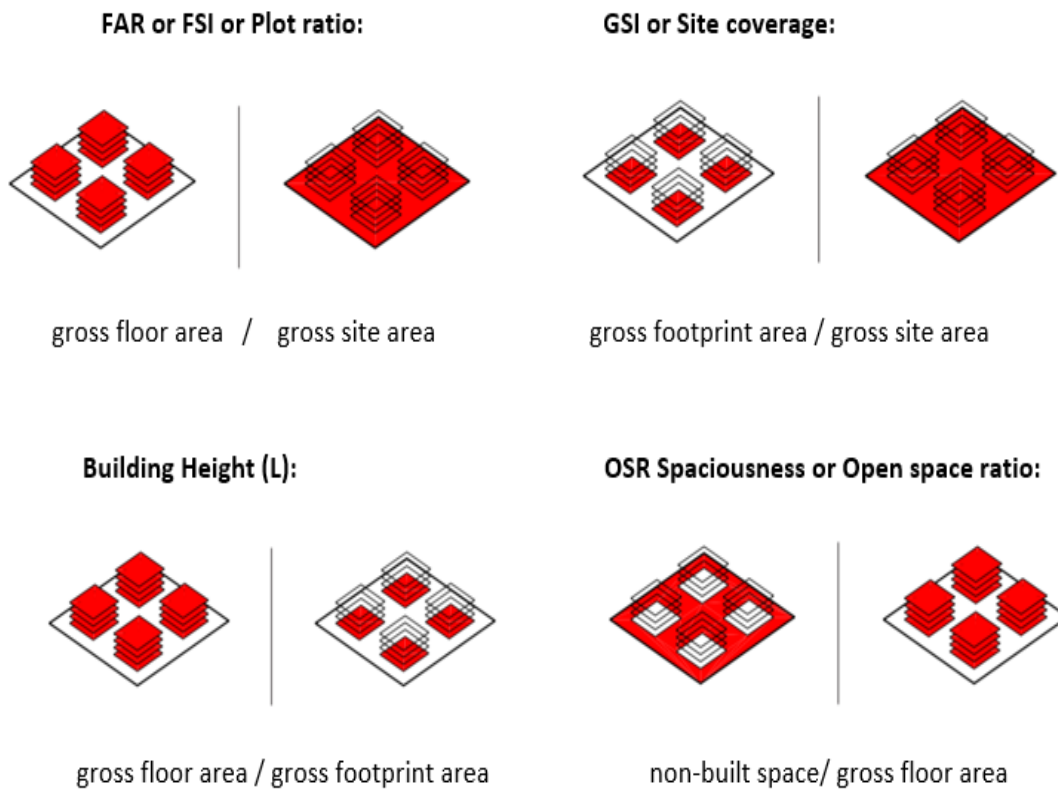


Figure 2.18. Schematic representation of the indicators in the diagram (Pont & Haupt, 2009 , p,96)

Similarly, MIT Urban Studies and Planning department developed Density Atlas⁶ to measure density, combining four metrics floor area ratio, site coverage ratio, dwelling density and population density.

As seen in Table 2.2 (p. 32), building height, distance between buildings, floor area ratio, site coverage ratio, and aspect ratio are some of the parameters in energy and UHI studies. Researchers tended to use simultaneously more than one of these metrics to understand how density affects energy consumption and/ or passive/active energy generation. Research findings pointed the importance of taking into account trade-offs while examining density- energy relation.

⁶ For more information, refer to <https://densityatlas.org/>

To illustrate, Godoy-shimizu et al. investigated heating demand and density relation for London residential buildings. They used floor area ratio and site coverage ratio as density indicators and revealed that buildings' energy demand was decreasing with increasing density (Godoy-shimizu et al., 2021).

Kanters and Wall investigated buildings' solar energy potential in Swedish climate conditions by using floor area ratio and building height as density indicators. They calculated load match percentages - the ratio of annual energy production to energy consumption- for every design option. Their findings revealed that load match percentages were decreasing with increasing density (Kanters & Wall, 2014).

Yin et al. examined the impacts of urban form on urban heat island intensity in Wuhan, China. They used building density and floor area ratio as density indicators. Study findings revealed that UHI intensity was increasing with increasing density (Yin et al., 2018).

2.2.1.1.2 Diversity (Mixed-use)

Diversity refers to “mixed-use” of the land for various purposes such as residential, commercial, recreational, industrial, and previous research show that mixed-use levels have a considerable influence on travel behaviors (Cervero & Kockelman, 1997; Manaugh & Kreider, 2013; L. Zhang et al., 2012). When business, commercial, and entertainment areas are located separately and far from residential areas, people are forced to use more motorized transportation to reach their needs. As the mixed-used levels of land increase, people can meet their needs by walking or bicycle (Manaugh & Kreider, 2013). Mixed land uses are closely related to the energy consumption of cities considering their impact on travel behaviors; properly mixed land uses help reduce travel energy demand. (L. Zhang et al., 2012; Zhao et al., 2017)

Researchers suggested several indicators to quantify diversity. For example, van den Hoek suggested mixed-use index (MXI) which refers to ratio of total residential floor area to total floor area in a defined area (van den Hoek, 2008). Figure 2.19 shows the explanation of the metric.

MXI value	0	50	100
<i>Meaning</i>	<i>No housing present</i>	<i>50/50 balance housing non-housing</i>	<i>100 % residential use</i>
<i>District type</i>	<i>Single use.</i>	<i>Mixed-use</i>	<i>Single use</i>
<i>Examples</i>	<i>Office park Factory Complex Harbor district Shopping center</i>	<i>City Center Semi Central</i>	<i>Newtown The projects Suburbia</i>

Figure 2.19. Definition of the mixed-used index (van den Hoek, 2008)

Bourdic et al., suggested “structural objectivity” to calculate the difference between the targeted distribution and the current distribution, with the aim of considering the objectives identified by policy makers and local authorities (Bourdic et al., 2012).

Frank and Pivo proposed “entropy” (Frank and Pivo, 1994), which became one of the most widely used indicators (Manaugh & Kreider, 2013). Entropy value changes between 0 to 1. 0 represents the worst mixed-use level.

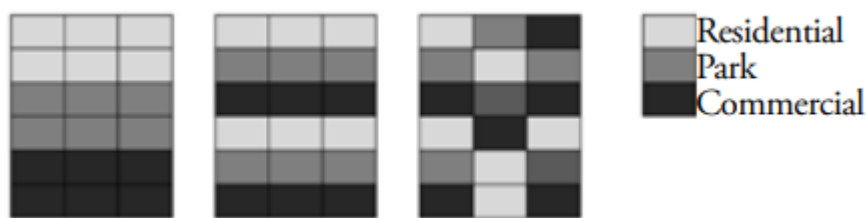


Figure 2.20. Three different mixed-use land configurations with the same entropy (Manaugh & Kreider, 2013)

However, using entropy may be deceptive in some cases (Cervero & Kockelman, 1997; Manaugh & Kreider, 2013). Figure 2.20, which shows three different mixed-use land configurations with the same entropy level is an example for this.

As a result, Cervero and Kockelman, 1997 proposed “dissimilarity index,” which measures the degree of variation in adjacent or diagonal uses of the hectare. Dissimilarity index value changes between 0 to 1. 0 represents the best mixed-used level. Figure 2.21 shows how to calculate the dissimilarity index (Cervero & Kockelman, 1997).

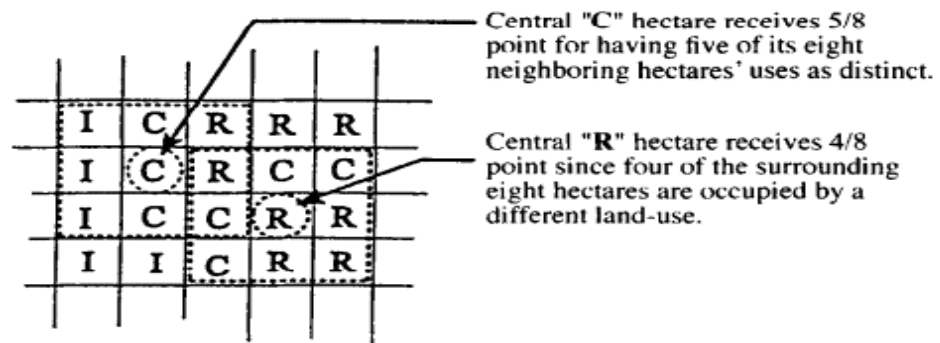


Figure 2.21. Schematic version of the dissimilarity index's calculation Source: (Cervero & Kockelman, 1997)

2.2.1.1.3 Green areas

According to Gago et al., 2013 one of the main reasons for the heat islands that occur in the summer months is the lack of greenery (Gago et al., 2013). Because green areas contribute to mitigating the heat island effect by evapotranspiration, shading, and natural ventilation (Ko & Radke, 2014). Wong et al. reviewed the effects of greening on surface temperature and concluded that green areas would lower the surface temperature by between 2 and 9 degrees Celsius. They declared that the green area's size, shape, how it was placed in the area, and plant species were influential in temperature reduction (Wong et al., 2021).

Besides improving outdoor thermal conditions, green areas also impact buildings' energy performance (Akbari et al., 1997; Donovan & Butry, 2009; Kong et al., 2016; B. Zhang et al., 2014). The findings of studies agree that green areas reduce the cooling energy needs of buildings.

Although its positive effects cannot be overlooked, green areas are not a frequently used urban form attribute, particularly in quantitative research in energy relevance. (Silva et al., 2017). Nevertheless, some indicators have been proposed in the literature to quantify green areas (Table 2.2, p.32).

For example, Bourdic et al. suggested spatial distribution index which quantifies “how evenly the green areas are distributed within a city”. The bigger the index, the better the distribution (Bourdic et al., 2012).

Both Ng et al. (Ng et al., 2012) and Ouyang et al., (Ouyang et al., 2020) used green coverage ratio – which refers to the ratio of total green areas to total site area- as an indicator to examine the cooling effects of vegetated areas in Hon Kong. They conducted parametric studies with varying green coverage ratios (between 0 to 56 percent and 2 to 56 percent, respectively).

Ng et al., concluded that an increase in the greening rate affected the urban microclimate positively, while Ouyang et al.'s finding reveals a non-linear relationship between coverage rate and cooling effect. Ng et al., suggested 30% of greenery for Hon Kong. Similarly, Ouyang et al. suggested 20-30% coverage. Moreover, in terms of the type of green areas, Ng et al., analyzed both trees and grass. Findings revealed that trees are more effective than grass in cooling effect, especially in green higher coverage ratios (Ng et al., 2012).

Jaganmohan et al., investigated how the green areas' size, shape, and type (park or forest) affect cooling in Leipzig, Germany. They used the mean shape index- which refers to the ratio of green area's perimeter to the total ground area- to quantify the shape effect. The study findings show that the impact of shape was not as strong as

the impact of the green area size. The higher the size was, the higher the cooling; urban parks cooling effect was not as high as urban forests (Jaganmohan et al., 2016).

2.2.1.1.4 Compactness

Although there is no widely accepted definition for the compact city, the common point of the definitions is that “compactness includes intensification of development” (Tsai, 2005). In the literature, there are many discussions on how a compact city should be, or in other words, which elements cities should have to be compact (Bay & Lehmann, 2017; Çalışkan, 2004; Jabareen, 2006; Jenks et al., 2005; Jenks & Burgess, 2004)

However, rather than discuss the urban compactness, this part discusses the compactness term for buildings in energy relevance. Here, compactness refers to measurement through the geometrical properties of buildings.

The shape of the building controls the exposed surface areas to the outside. That means building geometry affects the amount of solar exposure, heat losses, and daylight (Pacheco, Ordóñez, et al., 2012). According to Silva et al. "compactness may be seen as a proxy for building geometry"; therefore, compactness and buildings' energy performance relation is needed to pay attention (Silva et al., 2017). As the degree of compactness of buildings increases, they generally need less heating; on the other hand, they need more cooling. Compactness is counterproductive for heating and cooling, although not necessarily the same intensity (Silva et al., 2017).

In literature, several indicators are proposed to measure compactness, such as surface-to-volume ratio, form factor, size factor, built compactness (Table 2.2).

Researchers generally used surface-to-volume ratio (S/V) (or V/S). The smaller the surface-to-volume ratio, the more compact it will be.

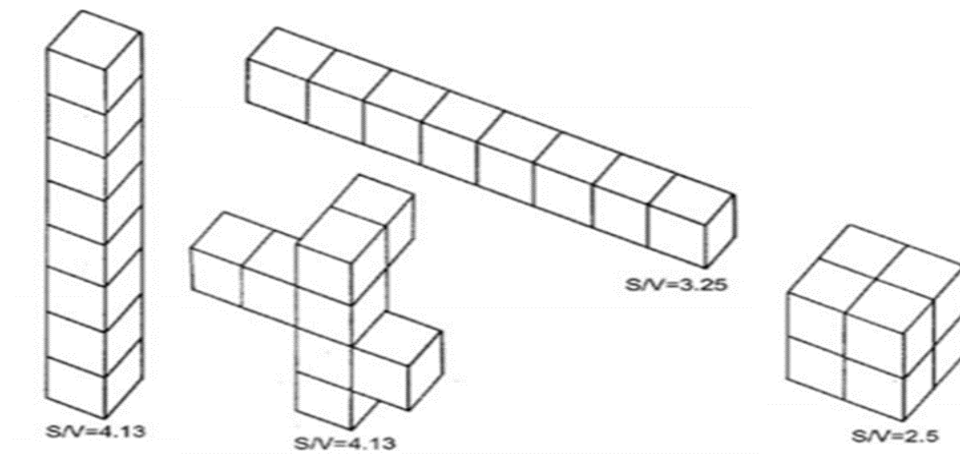


Figure 2.22. Examples of varying surface-to-volume ratios with the identical volume (Knowles, 1974)

For example, Gratia and Herde examined the relationship between building shape and heating consumption using Belgium's climate. Their findings revealed that the higher the surface-to-volume ratio, the higher the annual heating demand (Figure 2.23) (Gratia & Herde, 2003).

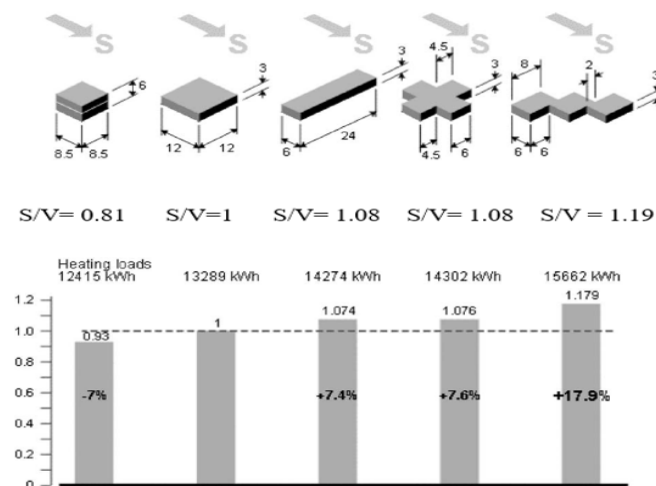


Figure 2.23. An example of the impact of the surface-to-volume ratio on buildings' heating demand (Gratia & Herde, 2003)

Mohajeri et al., examined the relationship between compactness and solar energy potential using volume-area ratio- which is the proportion of the total volume of buildings to total site area. The results indicated that as the compactness of the built environment increases, the potential to benefit from solar energy decreases (Mohajeri et al., 2016).

Marshall et al. developed "indicators that can capture compactness property in the urban context" for "providing an alternative to using density as a proxy for compactness." (Marshall et al., 2010) First, they proposed area compactness:

$$Compactness = \frac{4 * Area}{Diameter * Perimeter}$$

This measure can be thought of as the footprint area of the building (Fig. 2.24). By multiplying area compactness with the density (here density indicator is site coverage) obtained built compactness. Then:

$$Built\ Compactness = Compactness * \frac{Footprint\ Area}{Site\ Area} = \frac{4 * Footprint\ Area}{Diameter * perimeter}$$

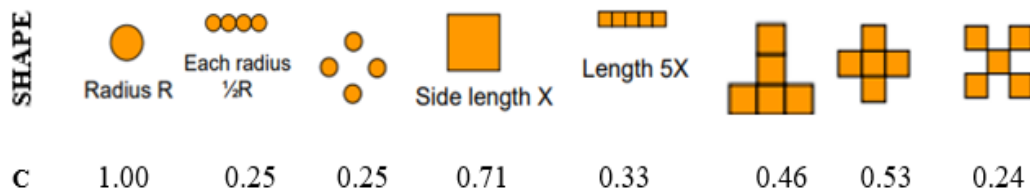


Figure 2.24. Calculation of area compactness (Marshall et al., 2010)

They applied this metric to English cities. Figure 2.25 shows the comparison of built compactness with density in the different cities.

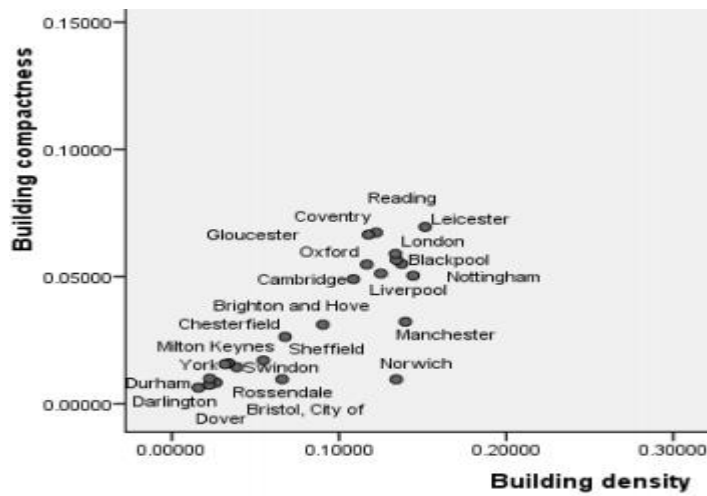


Figure 2.25. Comparison of built compactness with density (Marshall et al., 2010)

2.2.1.1.5 Shading

Mutual shading is an essential consideration for the energy performance of buildings in the urban context due to its influence on solar radiation gaining and daylight. To illustrate, Han et al. investigated the impact of shading on energy consumption in real urban cases in Italy and various climate conditions using hypothetical models. Their simulation findings revealed that heating and lighting demands were increased due to the shading effect. Moreover, the effect of shading was more significant in warmer climates and denser urban areas (Han et al., 2017).

Takebayashi et al. explored the potential of buildings in Osaka to generate solar energy. They concluded that the potential was reduced by 22.4 percent when the shading effect was considered compared to when the shading effect was not taken into account (Takebayashi et al., 2015).

On the other hand, the mutual shading effect does not always have adverse consequences. For example, Yu and Pan examined the shading influence in subtropical climate conditions, Hong Kong. Using four typical office buildings

cases, they performed simulations with and without considering the shading effects. Results showed that total annual energy demands could be reduced up to 8.48% by shading effects (Yu & Pan, 2018).

Sky view factor (SVF), urban horizon angle (UHA), obstruction sky view (OSV), and aspect ratio (H/W) are some indicators to measure the shading effect (Table 2.2).

In the literature, the **sky view factor**, which is “the fraction of visible sky” (Dirksen et al., 2019), primarily used in UHI studies. Past studies’ results showed a significant correlation between urban heat island intensity and sky view factor. (e.g., (Cheung et al., 2016; Yin et al., 2018; Yuan et al., 2011). Also, Poon et al. investigated the solar power generation potential of buildings in Singapore. SVF showed the most significant correlation among the ten selected morphological indicators (Poon et al., 2020).

According to Ratti and Richens (Ratti & Richens, 2004) :

“The view factor from the city to the sky, which represents the openness of the urban texture to the sky, takes part in three major environmental processes: the loss of longwave radiation from city to sky, responsible for the cooling down of the urban surface during the night; the absorption of solar shortwave radiation, causing daytime heating; and the illumination received on a horizontal plane from an overcast sky, which determines daylight potential.”

SVF values change between 0 to 1. The higher the value, the more visible sky. Several SVF estimation methods are available in the literature. Miao et al. reviewed the methods for calculating SVF values in detail, and they grouped them under five categories as “geometric methods,” “fish-eye photographic methods,” “global positioning system methods,” “simulation methods,” and “big data approaches” (Miao et al., 2020). Fig 2.26 shows illustrated version of some of the SVF calculations.

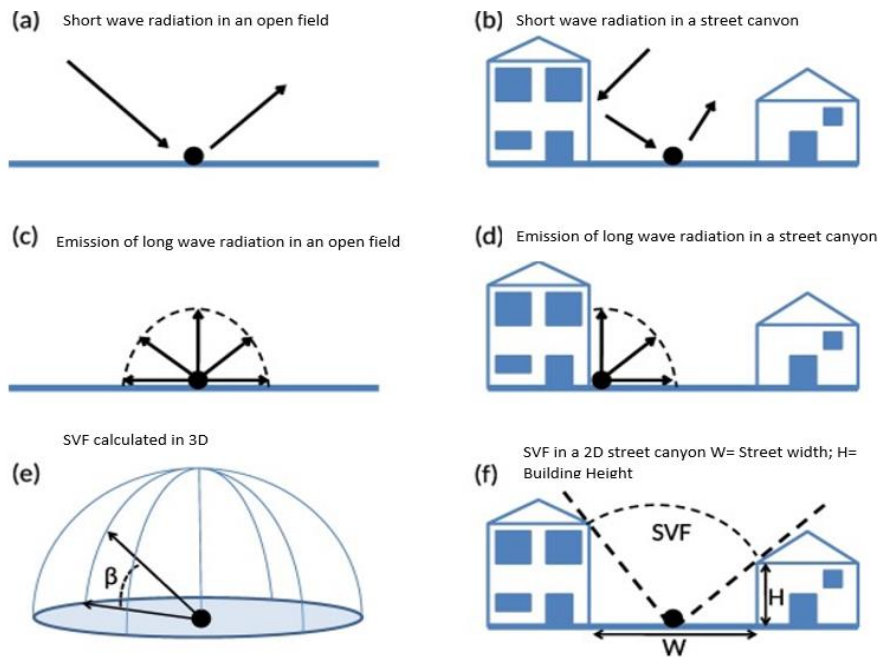


Figure 2.26. Illustration of some of the SVF calculations (Source: (Dirksen et al., 2019))

Aspect ratio, which is the ratio of building height to street width, is another helpful indicator to consider inter-building relations in performance evaluation studies. Past study findings revealed that aspect ratio has significant effects on urban heat island intensity (Oke, 1981; Theeuwes et al., 2014), daylight availability (Strømman-Andersen & Sattrup, 2011), solar energy potential (Hachem et al., 2013), and energy demand (Ali-toudert, 2009).

Theeuwes et al., drew attention to two critical mechanisms while explaining the relationship between aspect ratio and UHI. First, due to the “trapping of longwave radiation”, heat is trapped inside the canyon as building heights increase and street widths decrease. This heat causes an increase in temperature in the canyon, thus increasing the UHI effect. Secondly, the “shading effect” is more significant in canyons where the street width is narrow, and the building heights are high; that means the canyon has a lower temperature during the day. Due to the high thermal

inertia, relatively lower temperatures are observed in the canyon at night. Thus, a higher aspect ratio results in lower UHI (Theeuwes et al., 2014) (Fig 2.27).

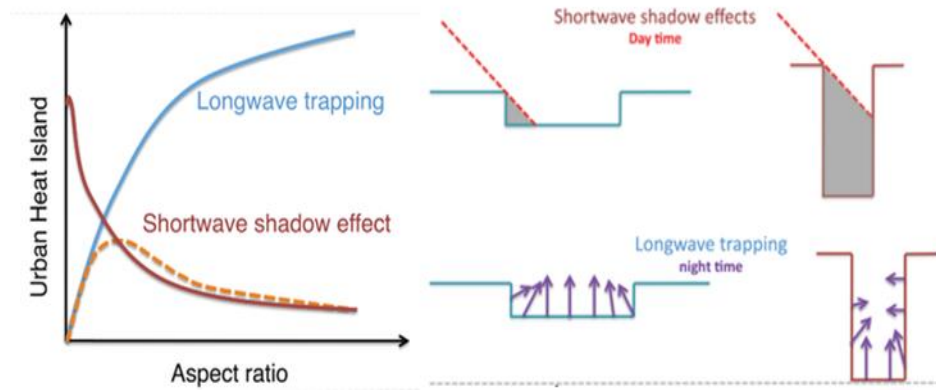


Figure 2.27. The effect of aspect ratio on UHI (Theeuwes et al., 2014)

Ratti et al., proposed the **urban horizon angle (UHA)** and the **obstacle sky view angle (OSV)**. As with the aspect ratio, these indicators are also based on the relationship between building height and street width (Ratti et al., 2005).

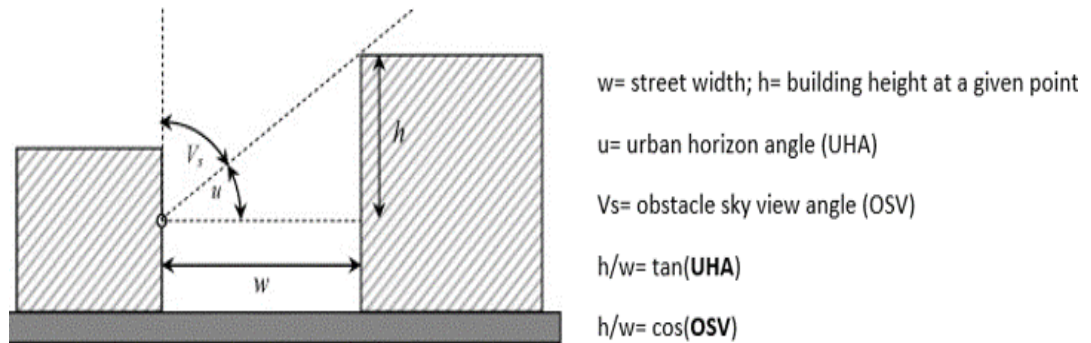


Figure 2.28. Calculation of the UHA and OSV (Robinson, 2006)

2.2.1.1.6 Passivity

As mentioned in the compactness part, built shape controls energy demand and solar exposure, as well as daylight availability. Ratti et al., developed the “passive zone concept” to be able to “quantify the potential of each part of a building to use daylight, sunlight, and natural ventilation.” (Ratti et al., 2005).

Passive zones are those parts of the building that are “naturally lit and ventilated”- extend approximately 6 m, twice the height of the ceiling from the façade (Fig 2.29); the remaining parts are called non-passive zones (Ratti et al., 2005). They suggested to use the ratio of passive zones to non-passive zones as a metric. Although this metric seems to affect only the building design, it is considered an urban form parameter since it affects the shape of the building (Borlin et al., 2013).

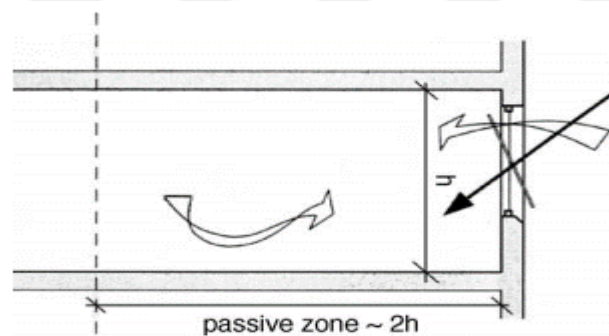


Figure 2.29. Visual version of the “passive zone” (Source: (Ratti et al., 2005))

It is expected that the higher the passivity ratio, the better will be the energy performance. However, high fenestration ratios and poorly insulated façades may result in excessive heat loss in winter and overheat in summer; in these cases, passive zones may cause more energy consumption than non-passive parts (Ratti et al., 2005). On the other hand, Salat and Bourdic argued that the passivity ratio should be kept high, considering that since the passivity rate is closely related to the shape of the building, and the change in the shape of the building is not possible -except

destroy or rebuilt-, while improving the insulation of the building is entirely possible (Salat & Bourdic, 2015).

Zhu et al., examined the impact of climate on the energy performance of passive zones and non-passive zones in an office building in three Chinese cities. Their findings revealed that climate conditions' effect was significant. In Urumqi, which has severe cold climate conditions, non-passive zones performed better. In the other two cities Beijing and Lhasa, which have warmer climate conditions, passive zones oriented to the south performed better (Zhu et al., 2018).

2.2.1.1.7 Orientation

Orientation, which refers to the angle of deviation of a surface from the true north, is essential for the energy performance of the buildings in two ways. First, the orientation of buildings affects how much sun they are exposed to, thus controlling the amount of energy consumption (Aksoy & Inalli, 2006), energy production potential (Hachem et al., 2013), and access to daylight (Samuelson et al., 2016). Second, street orientation affects the ventilation and mutual shading, thus UHI intensity (Aleksandrowicz et al., 2017; Gago et al., 2013).

It is generally accepted that orientation to the south in the northern hemisphere and to the north in the southern hemisphere gives better results (Pacheco, Ordóñez, et al., 2012). The below two studies' results support these widely accepted rules.

Aksoy and Inalli investigated the built shape and orientation impact on building's heating demand in both insulated and non-insulated conditions. They used the climate data of Elazığ, Turkey, which has a continental climate.

Their findings showed that up to 36 percent of the energy could be saved by appropriately combining the mentioned parameters. All buildings performed better when their longest wall oriented south, and square buildings performed worst with 45° (Aksoy & Inalli, 2006).

Hachem et al. investigated impact of orientation and aspect ratio on energy demand and solar energy generation using the climate data of Montreal, Canada, which has a humid-continental climate. They concluded that south orientating is the best performed option both consumption and generation (Hachem et al., 2013).

DeKAY and Brown pointed out that it is more difficult to create the appropriate orientation in mixed climates (DeKAY & Brown, 2014):

“The mix of heating and cooling needs translates to criteria for the urban pattern to admit sun and block wind (cold climate), to admit wind and block sun (hot climate), or to accommodate some mix of both needs (mixed climate)”

They recommended some neighborhood configurations for various climates (Figure 2.31). Also, they highlighted the importance of latitude in determining the street orientation since the shading patterns changes with latitude (Fig 2.30).

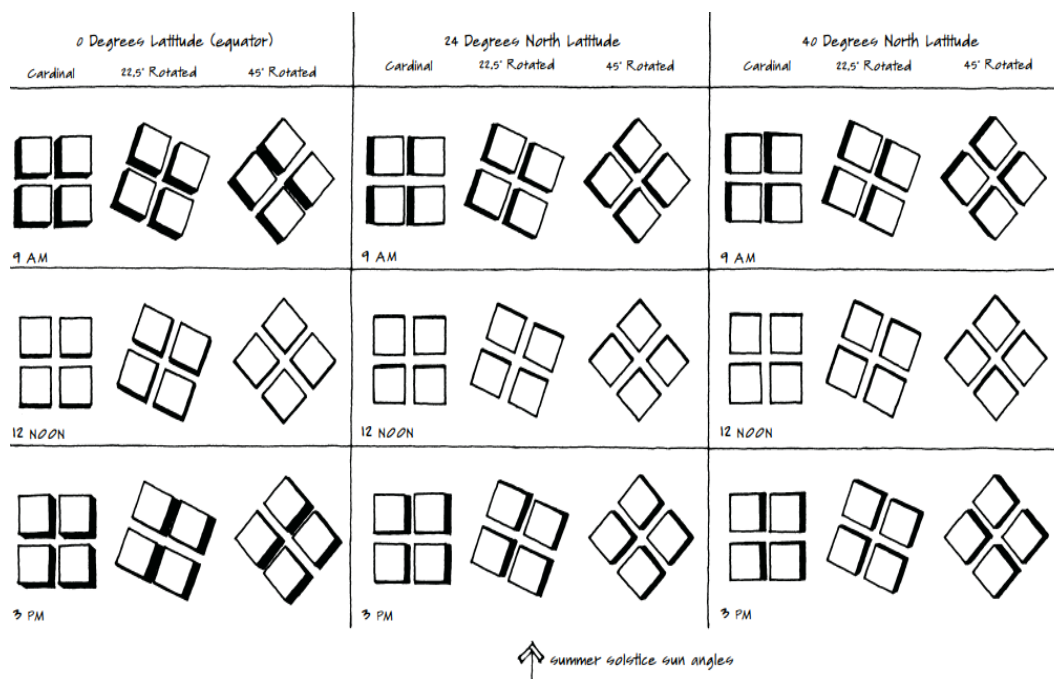


Figure 2.30. Shading patterns in the Northern hemisphere at different latitudes ((DeKAY & Brown, 2014), p141)

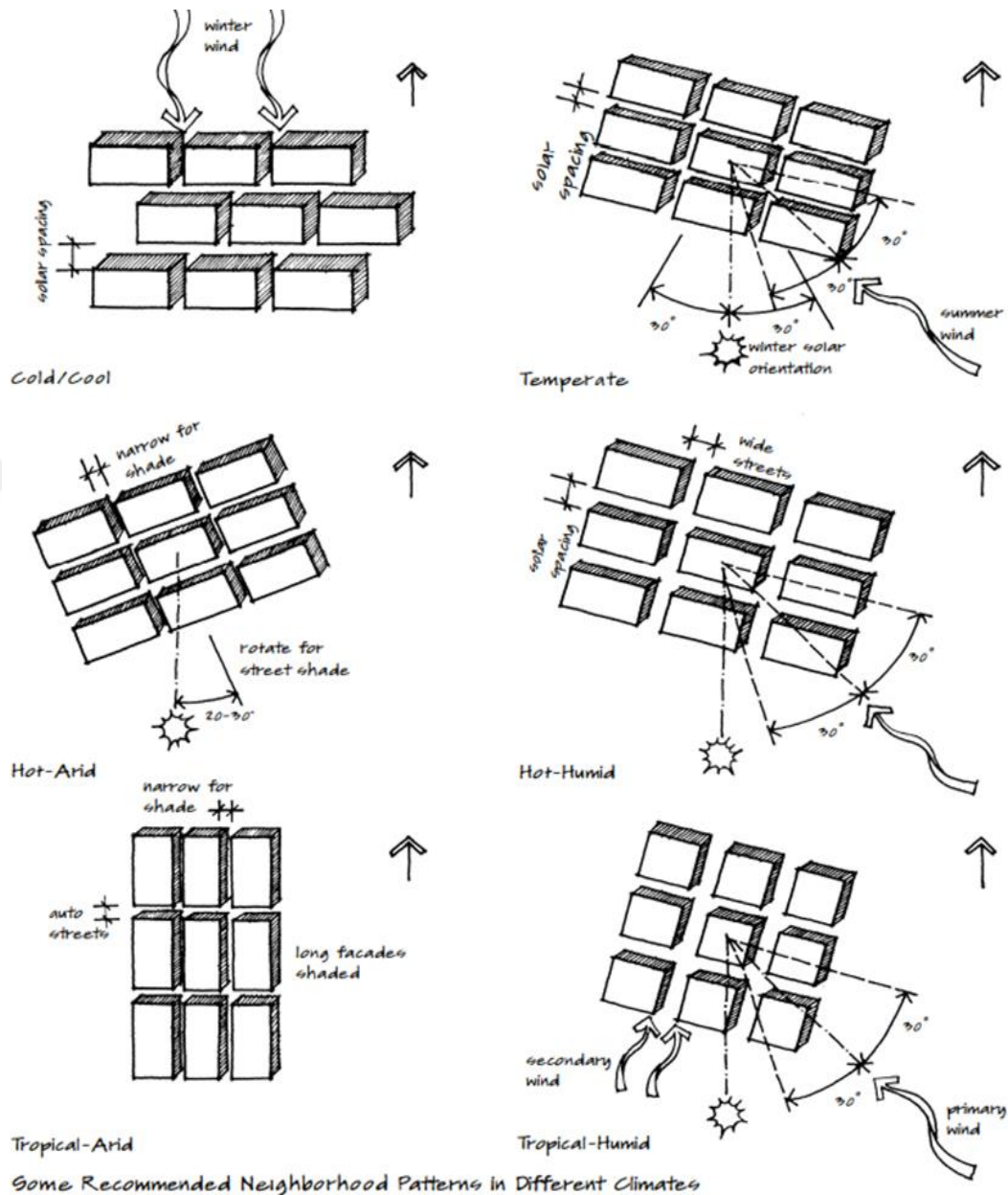


Figure 2.31. Neighborhood configurations recommendation for various climates ((DeKAY & Brown, 2014), p140)

2.2.1.2 Built Form/Shape

Previous research findings revealed that building form/shape effect is significant on energy performance in the urban context. Although it often has limitations due to lack of space availability, researchers frequently used building shape as a parameter in energy performance studies (Amaral et al., 2018). However, how did they include them in their research is worth reviewing.

Analyzing building stocks' energy performance is more challenging at the urban level, and it may not be feasible for every single building to be analyzed in detail, so researchers need to limit the number of buildings. (Monteiro et al., 2017). As such, to deal with this complexity, they have created building archetypes based on statistical data and predictions, which can be a reference point for calculating the energy performance of a neighborhood or a city (Amaral et al., 2018).

Also, researchers have preferred hypothetical models in many studies. Unlike a case study approach, using hypothetical models as a reference point does not benefit from applying reliable real-life conditions. On the other hand, since the content of urban performance studies expanded and the interactions between design parameters became increasingly complex, researchers considered the necessity to develop flexible analytical environments; hypothetical typologies reflect this need (Natanian, Aleksandrowicz, et al., 2019b).

In their book, "Urban Space and Structures", Martin and March discussed the question, "What form of building makes the most effective use of land?" In one part of the book, they addressed the question, "How can such a problem be studied in a systematic manner." They classified the built forms and presented three uniform typologies: pavilion, street, and court, namely. They examined the relationship between the built potential to the number of floors (Martin & March, 1972). Figure 2.32 shows these built forms.

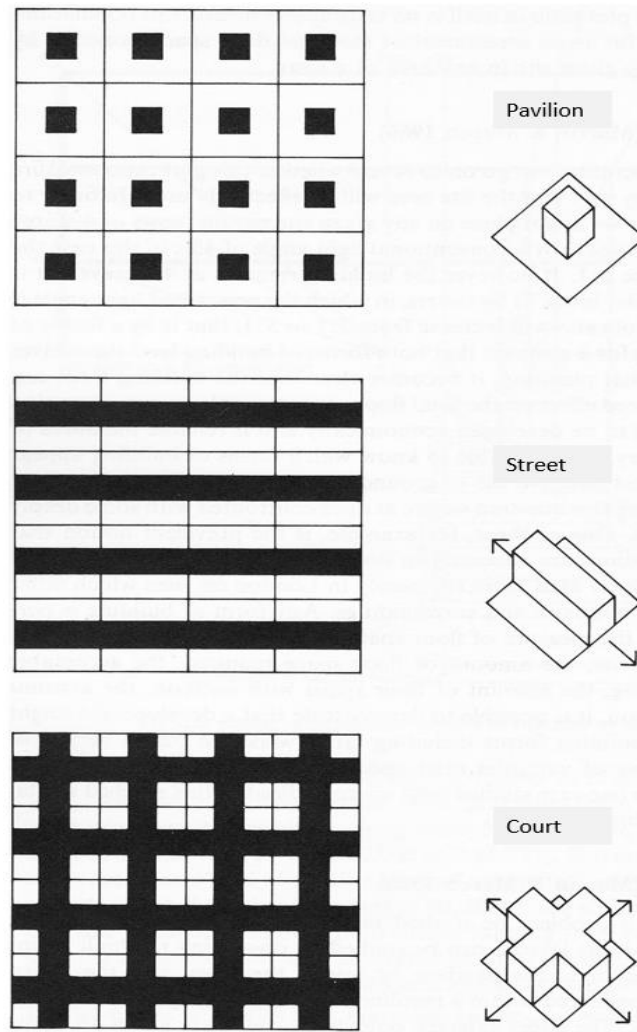


Figure 2.32. Generic built forms: pavilion, street, court. (Martin and March, 1972, p36)

Following Martin and March, Ratti et al. expanded on the building form analysis and re-evaluated these forms in terms of environment and energy. In the first part, using the image processing technique, they analyzed daylight availability and solar exposure through six generic forms (Figure 2.33, top) In the second part of the study, they performed a case study located in the hot arid climate. They adapted the generic forms in the first part and determined three different built forms representing the local archetypes (Figure 2.33, bottom) (Ratti et al., 2003).

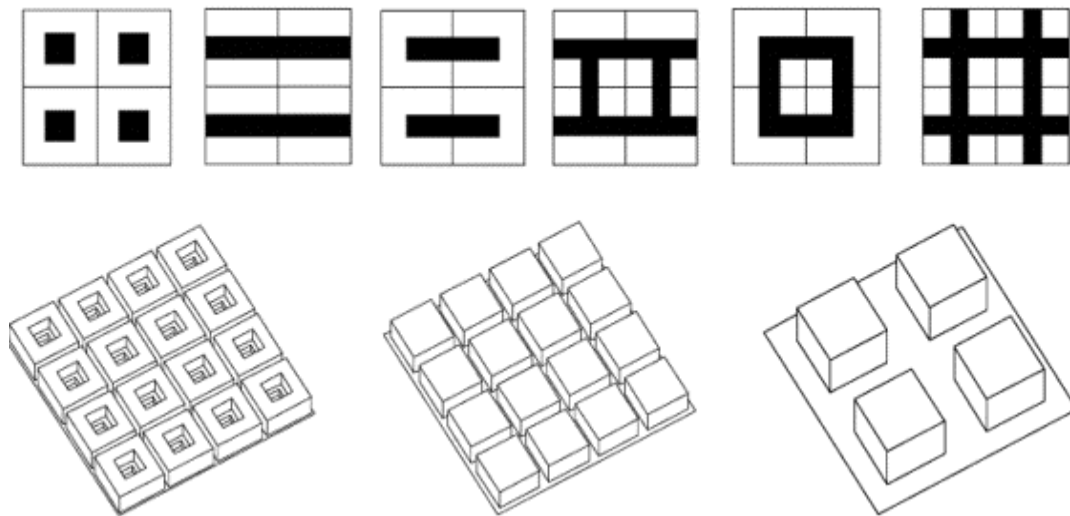


Figure 2.33. Generic built forms (top); and the built forms representing the local archetypes (bottom) (Ratti et al., 2003)

In their parametric research, Kanters and Wall identified four types of urban blocks: Strip (street) 50×50 m, closed (court) 80×60 m, closed 50×50 m, and U-form 50×50 m. Using the climatic conditions of the city of Lund, located in the southern part of Sweden, they studied the solar energy potential of urban blocks of varying densities, roof types, and orientations (Figure 2.34) (Kanters & Wall, 2014).

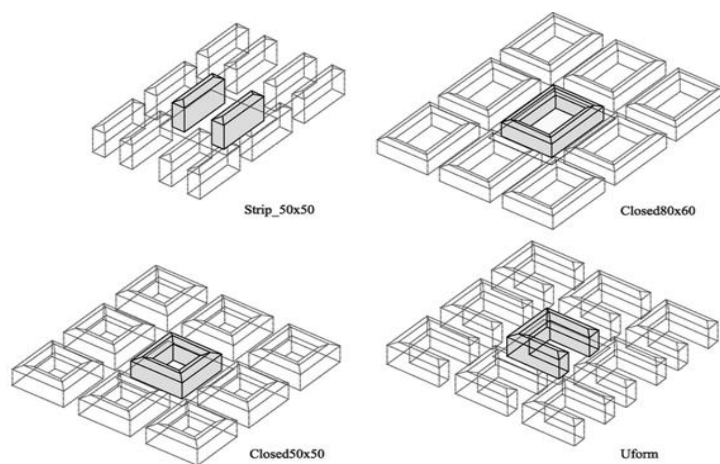


Figure 2.34. Identified built forms for Lund, Sweden (Kanters & Wall, 2014)

J. Zhang et al. evaluated how building form affects building cooling demands. They used Singapore's climate data for simulations and identified thirty-four hypothetical generic forms as a variation of six typical building form typologies: compact; U-shape, L-shape, courtyard, low-rise, row house, linear slab, and high-rise tower block (Figure 2.35) (J. Zhang et al., 2015).

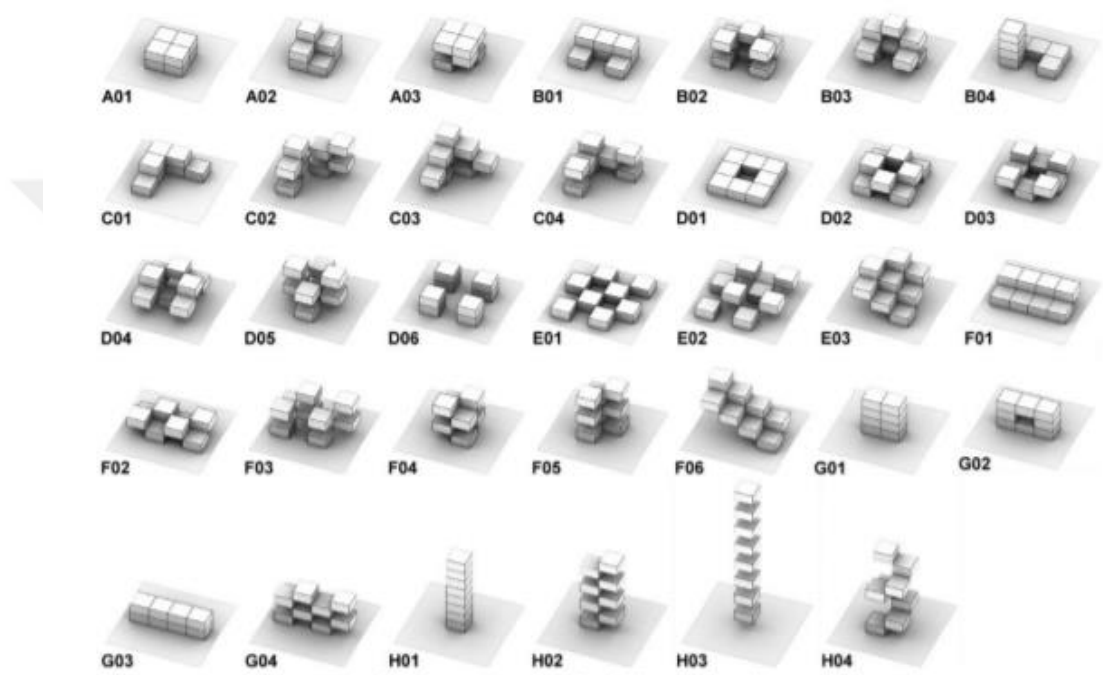


Figure 2.35. Generic building typologies representing Singapore (J. Zhang et al., 2015)

Similarly, Natanian et al. examined how the urban form, daylight performance, and energy performance interact in the hot and dry, Mediterranean climates. They used the climatic conditions of the city of Tel Aviv and identified five representative typologies: scatter (pavilion), high-rise (high-rise pavilion), slab (street) with two different orientations, and courtyard (Natanian, Aleksandrowicz, et al., 2019b).

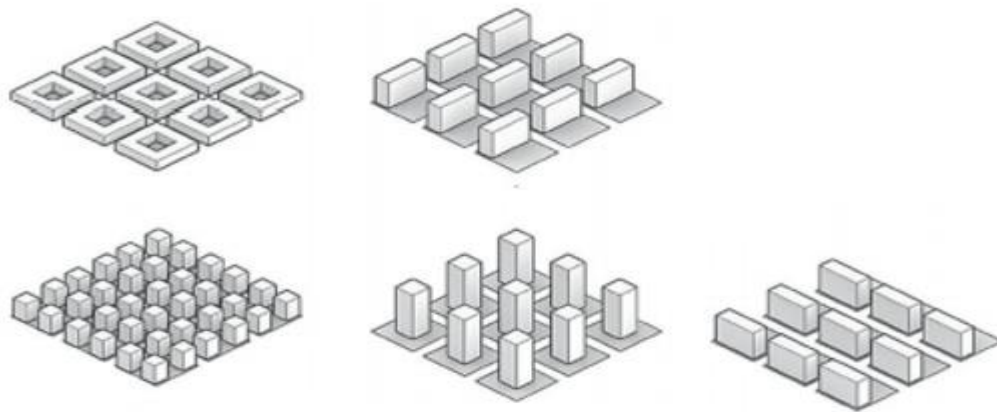


Figure 2.36. Five representative built forms for Tel Aviv, Israel (Natanian, Aleksandrowicz, et al., 2019b).

2.3 Research Approaches and Tools for Evaluation

Energy modeling⁷ is an essential part of urban energy performance evaluation. They contribute to the decision-making and planning process by providing quantitative results. Due to buildings have high- potential for energy efficiency, they play a crucial role in urban energy modeling (Frayssinet et al., 2018; Swan & Ugursal, 2009)

Building energy models have been used for almost fifty years to foresee their energy use (Lim & Zhai, 2017). Depending on the study's aim, content, and scale, different urban building modeling approaches, and tools exist in the literature to address the energy performance of buildings. This part aims to review them.

⁷ Modeling means “the activity of using mathematical models (= simple descriptions of a system or process) to make calculations or predict what might happen.” (Cambridge Dictionary, n.d)

2.3.1 Urban Building Energy Modeling (UBEM) Approaches & Tools

As mentioned at the beginning of this literature review chapter, the collected reviews were separated into two groups. The first group has been used for providing a general overview of how urban planning and design literature address climate change, energy performance, and urban heat island studies. The second group, shown in Table 2.3, is used for reviewing the existing modeling approaches, evaluation methods, and tools used while evaluating the energy performance of building stocks in the urban context.

Table 2.3 Selected Reviews Published on Research Approaches, Evaluation Methods and Tools

Reference	Focus of the Review
(Abbasabadi & Mehdi Ashayeri, 2019)	Urban energy use modeling
(Ali et al., 2021)	Systematic review of urban building modeling
(Allegri et al., 2015)	Modelling approaches/ tools for district-level energy systems.
(Ferrando et al., 2020)	Physics-based UBEM tools, comparing them from a user-oriented perspective.
(Frayssinet et al., 2018)	City energy simulation models and the related modeling techniques.
(Hong et al., 2020)	UBEM research and applications
(Johari et al., 2020)	UBEM challenges/ shortcoming/ future possibilities
(Kavgic et al., 2010)	Bottom-up UBEM approaches
(Lauzet et al., 2019)	Review of the methods currently used to account urban microclimate in building design simulations.
(Lim & Zhai, 2017)	Building stock energy consumption modeling approaches

Table 2.3 (Continued)

(Li et al., 2019)	Research on UHI impacts on building energy performance and their UHI modeling approaches
(Mauree et al., 2019)	Assessment methods for climate adaptation of future cities
(Reinhart & Davila, 2016)	Bottom-up UBEMs by discussing how they organize simulation input, generate thermal model, validate results.
(Swan & Ugursal, 2009)	Modeling techniques used for residential energy consumption

2.3.1.1 UBEM Approaches

Urban building energy modeling is a concept that refers to the computational modeling of groups of buildings rather than stand-alone buildings, where the interaction between buildings can also be considered (Hong et al., 2020).

The temporal and spatial scale limits of UBEM differ according to the intended use. Modeling can be done for a group of ten buildings or larger scales, including the entire city stock. Time scales can also be modeled, typically ranging from one hour to several decades (Hong et al., 2020).

In the existing literature, urban building energy modeling approaches can be classified into two groups: top-down and bottom-up regarding what kind of data they used. According to Swan and Ugursal (Swan & Ugursal, 2009):

“The top-down approach treats the residential sector as an energy sink and is not concerned with individual end-uses. It utilizes historic aggregate energy values and regresses the energy consumption of the housing stock as a function of top-level variables such as macroeconomic indicators (e.g., gross domestic product, unemployment, and inflation), energy price, and general climate. The bottom-up approach extrapolates the estimated energy consumption of a representative set of individual houses to regional and national levels....”

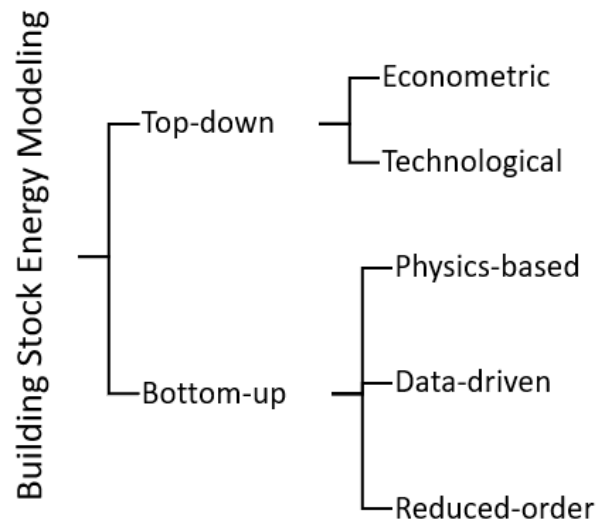


Figure 2.37. Classification of the building stock energy modeling approaches
Source: (Ali et al., 2021; Hong et al., 2020; Kavgic et al., 2010; Swan & Ugursal, 2009)

Top-down models can further be divided into two groups: econometric models, and technological models (Kavgic et al., 2010; Swan & Ugursal, 2009).

Econometric models focus on the economic performance of the building stock at a large scale. They use for predicting the social-economic policies effects. They provide insights into how various "what if" scenarios affect the economy using the interplays between the energy sector and socio-economic factors (Lim & Zhai, 2017; Swan & Ugursal, 2009).

Technological models, rather than modeling technological changes or improvements, focus on the typical characteristics of building stocks, such as which equipment they have or not. Then, they relate energy demand to the characteristic features of the building stock (Kavgic et al., 2010; Swan & Ugursal, 2009).

Ali et al. reviewed urban energy modeling research systematically, and their findings revealed that top-down models are primarily used for energy evaluation, planning and optimization purposes (Ali et al., 2021).

Bottom-up models can further be divided into three groups: physics-based engineering models, data-driven models, and reduced order models (Ali et al., 2021; Hong et al., 2020).

Physics-based engineering models use simulation technics and require detailed input data for describing the building with all its features, such as geometric features of the building, material properties, occupancy characteristics, and climatic information (Johari et al., 2020; Lim & Zhai, 2017). They have a heavy computational load (Swan & Ugursal, 2009). Therefore, researchers identify archetypes that represent the whole building stock to reduce computation load and time (Abbasabadi & Mehdi Ashayeri, 2019; Johari et al., 2020). These models are primarily used for energy evaluation, optimization, and prediction purposes (Ali et al., 2021).

Data-driven models include statistical and artificial intelligence-based models. They use empirical data, which makes them more realistic in terms of identifying the energy needs. However, they need large data sets (e.g., billing data) that collect survey-based questionnaires. So, whether the models give realistic results is highly dependent on the availability and characteristic of the data (Abbasabadi & Mehdi Ashayeri, 2019). These models are primarily used for energy evaluation and energy prediction purposes (Ali et al., 2021).

Reduced-order models can be thought of as a hybrid form of physics-based and data-driven models. These models aim to combine the advantages of both models. Compared to the other two approaches, it requires fewer input data and takes less time to calculate. Estimation of parameters relies on standardization (e.g., the European Committee for Standardization (CEN) and the International Organization for Standardization (ISO)), and the main challenge of these models is trade-offs between simplicity and accuracy (Ali et al., 2021; Hong et al., 2020). These models are primarily used for energy prediction and evaluation purposes (Ali et al., 2021).

As table 2.4 shows in more detail, bottom-up and top-down approaches have similarities and differences; each has advantages and disadvantages. The essential factor in determining the modeling approach is the purpose for which the model will be used and the questions for which answers are sought (Hong et al., 2020)

To illustrate, using top-down models can provide insight into these scenarios: "what will happen if more of certain buildings are to be built" or "what will happen if building types are to be converted to another specific building type." However, as these models are based on historical data, they are not well suited for supply-demand scenarios that integrate energy to an identified district (Reinhart & Davila, 2016) and integrate technological developments (Johari et al., 2020). Similarly, since data-driven models use historical data, they are not very well suited for studies investigating the impact of recent technologies (Ali et al., 2021).

On the other hand, since physics-based bottom-up models deal with the characteristics of each building offer flexibility for scenarios involving technological advances and energy efficiency (Lim & Zhai, 2017). They are more suitable for evaluating energy efficiency scenarios or strategies such as retrofit. Furthermore, in these models, it is possible to apply renewable energy technologies (Abbasabadi & Mehdi Ashayeri, 2019).

Table 2.4 The advantages and disadvantages of top-down and bottom-up modeling approaches. Source: (Abbasabadi & Mehdi Ashayeri, 2019; Ali et al., 2021; Lim & Zhai, 2017; Swan & Ugursal, 2009)

	Top-down Models	Bottom-up Data-Driven Models	Bottom-up Physics-Based Models	Bottom-up Reduced order Models
ADVANTAGES	-Forecasting long-term energy consumption - Involving macroeconomic and socioeconomic factors - Encompassing trends, avoiding detailed technology descriptions	-Encompassing occupant behaviors -Enabling to determine a typical end-use energy consumption -Incorporating occupancy and socioeconomic factors -Not required detailed data (uses billing data and simple survey information)	-Enabling to model current and prospective technologies in detail -Assess and quantify the impacts of different combinations of technologies -Not dependent on historical data -Estimating energy use by individual end-uses	-Combining physics-based and data-driven approaches - Relying on fewer input information - Providing more flexibility for optimization -Delivering optimal computational efficiency
DISADVANTAGES	-Relying on aggregated data -Depending on past energy-economy interactions to project future trends -Coarse analysis -Lack of explicit representation of end-uses	-Relying on historical consumption data -Limited capacity to assess the impact of retrofit or new technologies -Requiring large survey sample to exploit variety -Not cost effective when data is not available	-Relying on detailed input information -Simplification of building, urban and human related factors -No economic factors -Computationally intensive -Assumption of occupant behavior	- Assuming non-linear parameters or processes as linear - Simplifying areas of physical detail by averaging the localized properties - Produces model specific to applications and stakeholders -Provides limited scalability - Requires extensive calibration using measured data

2.3.1.2 UBEM Tools

Many UBEM tools have been developed during last decade (Ferrando et al., 2020), and the existing UBEM tools often apply a bottom-up approach (Abbasabadi & Mehdi Ashayeri, 2019). Table 2.5 lists some examples of the tools that applied bottom-up approach.

Table 2.5 Examples of UBEM tools. (Abbasabadi & Mehdi Ashayeri, 2019; Ali et al., 2021; Ferrando et al., 2020; Hong et al., 2020)

	Tool- Developer-Year	Output	Reference
Physics-Based	CityBES <i>LBNL-2015</i>	Building energy consumption, retrofits	(Hong et al., 2016)
	CitySim <i>EPFL-2009</i>	Building energy consumption, solar energy generation,	(Robinson et al., 2009)
	UMI <i>MIT-2013</i>	Building energy consumption, daylighting, walkability, embodied energy consumption	(Reinhart et al., 2013)
	URBANopt <i>NREL-2016</i>	District's renewable energy optimization	(Polly et al., 2016)
Data-Driven	CoBAM <i>ANL-2011</i>	Prediction of the impact of energy efficient technologies on buildings' energy performance	(Martinez-moyano, 2011)
	Energy Proforma <i>MIT-2010</i>	Building, industrial & transportation, embodied energy consumption	(MIT & Tsingua Univesity, 2010)
	UrbanFootprint <i>Calthorpe Analytics-2017</i>	Maps for measure risks and opportunities for access to land use, policy, resource	(Calthorpe Analytics, 2017)
Reduced Order	CEA <i>ETH Zurich-2016</i>	Energy systems' analysis & optimizations	(Fonseca et al., 2016)
	OpenIDEAS <i>KU Leuven- 2015</i>	Integrated building and district energy evaluation	(Baetens et al., 2015)
	SimStadt <i>University of Stuttgart -2013</i>	District's energy consumption	(Nouvel et al., 2015)
	TEASER <i>RWTH Aachen 2017</i>	Building energy consumption	(Remmen et al., 2018)

Many more tool examples can be found developed for UBEM. For UBEM tools developing integrated models remains a significant challenge (Ali et al., 2021; Johari et al., 2020). Although this will change soon, today, UBEM tools generally focus on a single issue of the energy process and are far from an integrated approach (Abbasabadi & Mehdi Ashayeri, 2019). There is no single model that can handle the entire process, and there is not yet a single tool that evaluates all factors simultaneously (Allegrini et al., 2015).

For example, most UBEM tools do their assessments without considering microclimate effects; only a couple of tools (e.g., CitySim and City Energy Analyst (CEA)) consider microclimate effects (Hong et al., 2020). Although coupling UBEM tools with other software is a solution, data management between different software is often cumbersome and limits the general user (Ferrando et al., 2020).

At this point, Grasshopper environment (see part 2.3.3), which provides convenience for dealing with these limits, has aroused researchers' interests. (Natanian, Aleksandrowicz, et al., 2019a). The first reason for this is that it allows combining various energy and environmental considerations in the same workflow. Another important reason is that it enables a parametric approach to evaluate many design alternatives simultaneously (Natanian, Aleksandrowicz, et al., 2019a).

The following part briefly presents how researchers combined microclimate and energy models to account UHI effect. Immediately after, before concluding the literature review chapter, the last part reviews how they benefited from Grasshopper environment for energy performance assessment.

2.3.2 Modeling UHI impacts on Building's Energy Performance

Lauzet et al. divided urban climate models into three groups according to their scale: street scale, neighborhood scale, and city-scale. Then they classified them according to their horizontal resolution, which corresponds to the horizontal dimension of the mesh elements used in the model (Figure 2.38) (Lauzet et al., 2019).

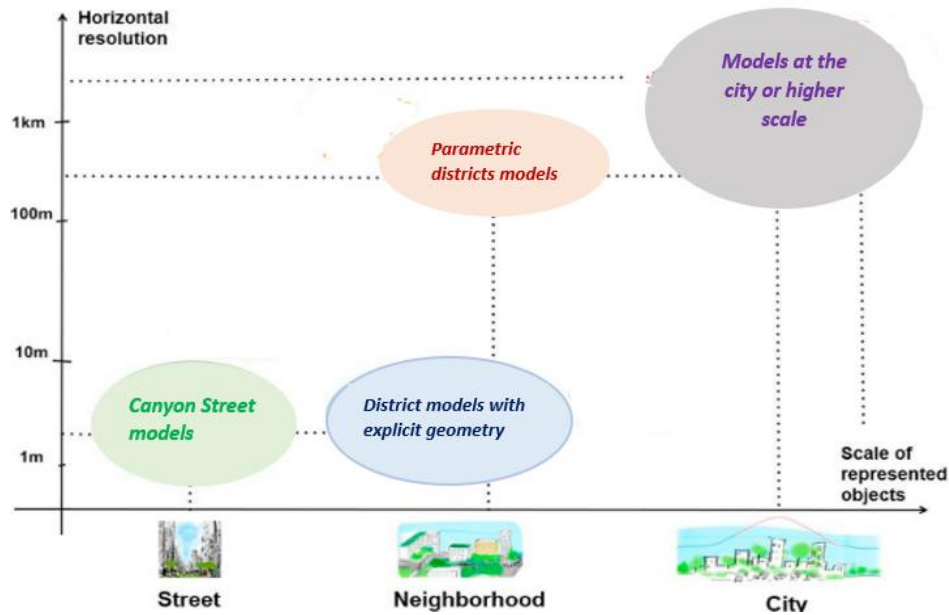


Figure 2.38. Urban climate models (Lauzet et al., 2019)

As seen in figure 2.38, city-scale models allow evaluating up to several kilometers; neighborhood-scale allows up to a couple of kilometers while street scale allows up to a hundred meters (Lauzet et al., 2019). A few tools exist in the literature suitable for assessment at an intermediate scale table 2.6 summarizes them with their capabilities.

Table 2.6 Tools for urban climate modeling (Lauzet et al., 2019; Mauree et al., 2019)

Category	Tool	UEC	OTC	YS	Reference
Parametric models	CAT	✓			(Erell & Williamson, 2006)
	CIM	✓		✓	(Mauree et al., 2017)
	UWG	✓		✓	(Bueno et al., 2013)
Explicit models	ENVI-met	✓	✓		(Bruse & Fleer, 1998)
	SOLENE-Microclimat	✓	✓		(Morille et al., 2015)
<i>UEC: Urban environmental conditions; OTC: outdoor thermal comfort; YS: Yearly Simulation</i>					

UWG (Urban Weather Generator) and ENVI-met are the most popular tools among researchers. UWG was developed to estimate the UHI effect. It modifies air temperature and humidity measurements, which are usually acquired outside the city, according to the conditions in the city, based on principles of conservation of energy (Bueno et al., 2013). ENVI-met was developed to predict urban surfaces' (e.g., materials), greenery, and atmosphere's effect on urban microclimate. Thus, small-scale design considerations can be examined, such as buildings' materials, ground material, green façades and roofs, and vegetations (Bruse & Fler, 1998).

Li et al. reviewed the research on UHI impacts on buildings' energy performance and reviewed how these studies account for the UHI impacts. They concluded that these studies were generally modeled to both take into account the UHI effect and not. The difference between the two assessments was considered as the effect of UHI on building energy performance (Li et al., 2019). Figure 2.39 shows the generic flowchart of these studies' approaches.

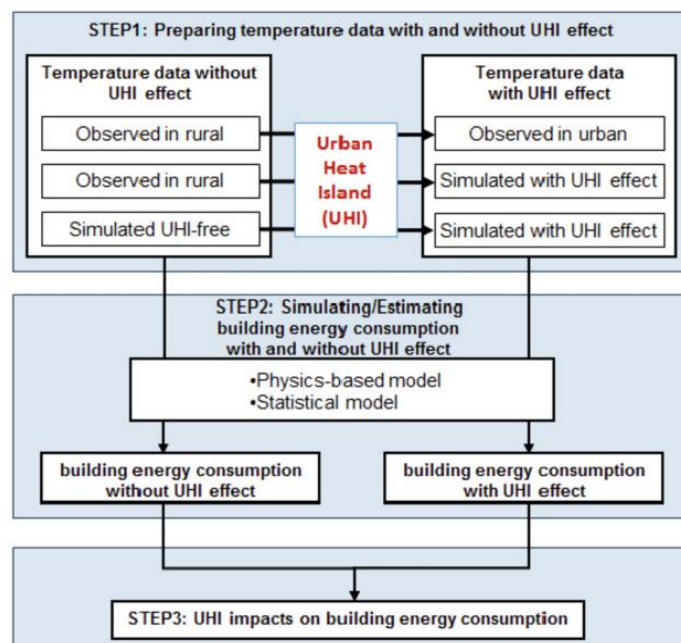


Figure 2.39. Generic Flowchart to account UHI impact on building energy consumption (Li et al., 2019)

2.3.3 Parametric Approach in Building Energy Performance Evaluation

Besides architecture and urban design, parametric design approach is used in a wide range of disciplines for many different objectives (e.g., shipbuilding, furniture design, fashion, jewelry design, structural analysis) due to its advantages (Eltaweel & SU, 2017).

Parametric means “relating to the parameters of something” where parameter means “a set of facts or a fixed limit that establishes or limits how something can or must happen or be done”⁸

Design elements can be defined as parameters in parametric design, which means simultaneous reshaping of the design by changing or reformulating these parameters. Thus, design variations can be easily achieved throughout the design process (Eltaweel & SU, 2017).

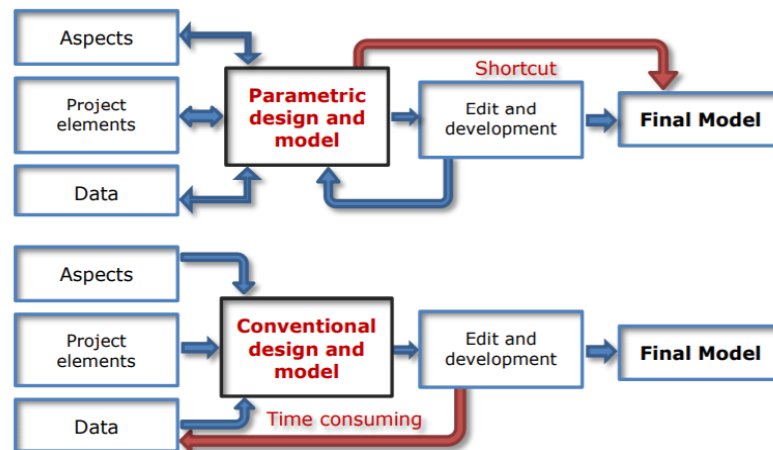


Figure 2.40. Representation of the design processes in the parametric model and the traditional model (Source: (Eltaweel & SU, 2017))

⁸ <https://dictionary.cambridge.org/dictionary/english/parametric>

The parametric design process is carried out through parametric models, representing the design in a computer environment. The advantage of using parametric models is that when the design elements- which are defined parametrically - change, it updates itself without deleting or redrawing the model (Hernandez, 2006). This quick response from the model can be considered a “shortcut” to reach the intended design variations (Eltaweel & SU, 2017) (Figure 2.40).

Many modeling tools were developed for parametric design. Rhino-Grasshopper, GenerativeComponents⁹, Autodesk-Revit¹⁰, CATIA¹¹ are some of these tools.

Grasshopper is one of the most preferred parametric modeling tools in architecture and urban planning/design discipline. It does not require programming and coding knowledge; within Rhinoceros, a 3D modeling CAD (computer-aided design) software, it is used for graphical algorithm editing¹².

Grasshopper is also gaining popularity among researchers focusing on energy and environmental analysis (Natanian, Aleksandrowicz, et al., 2019b). It has several plug-ins specialized in energy and environmental analysis (e.g., Ladybug Tools¹³ (Ladybug, Honeybee, Butterfly, and Dragonfly, namely) and Climate Studio¹⁴ (the newest version of DIVA4RHINO)). Apart from the programs specialized for environmental and energy analysis, there are also some plug-ins that facilitate the iteration process (e.g., Colibri¹⁵) or the optimization process (e.g., Galapagos¹⁶, Octopus¹⁷). All these plug-ins can effortlessly be combined with each other and with other open-source programs (e.g., Design explorer¹⁸). Therefore, it is advantageous

⁹ https://communities.bentley.com/products/products_generativecomponents/

¹⁰ <https://www.autodesk.com/products/revit/overview>

¹¹ <https://www.3ds.com/products-services/catia/>

¹² <https://www.grasshopper3d.com/>

¹³ <https://www.ladybug.tools/>

¹⁴ <https://www.solemma.com/climatestudio>

¹⁵ <http://core.thorntontomasetti.com/food4rhino-release-second-colibri-release/>

¹⁶ <https://onlinelibrary.wiley.com/doi/10.1002/ad.1568>

¹⁷ <https://www.food4rhino.com/en/app/octopus>

¹⁸ <http://core.thorntontomasetti.com/design-explorer/>

to create analysis flowcharts with multiple considerations in the grasshopper environment, and researchers benefited from this environment in their parametric studies.

To illustrate, Kanters and Wall used DIVA4RHINO to investigate buildings' solar energy potential and energy consumption using Sweden's climate data (Kanters & Wall, 2014). Fang combined Ladybug, Honeybee, Galapagos, and Octopus to optimize a building's daylight performance and energy performance using three different climate data in America (Fang, 2017). Naboni et al. used Ladybug tools and presented a flowchart for evaluating urban areas' regenerative performance (in addition to energy, daylight, UHI performance; outdoor thermal comfort analysis and nature-connectedness (biophilia) analysis also considered), then they tested the flowchart using Spain's climate data (Naboni et al., 2019).

Natanian conducted a series of research and combined Ladybug tools, ENVI-met, Colibri, Design explorer; presented various flowcharts for evaluating energy balance, daylight availability, urban microclimate, and outdoor thermal comfort; tested in Israel context (Natanian, 2020). Similarly, Ibrahim et al. presented a workflow that tested in Cairo, Egypt context. They used Ladybug tools, Colibri, Phyton script for evaluating energy demand and outdoor thermal comfort (Ibrahim et al., 2021).

CHAPTER 3

METHODOLOGY

This chapter presents the methodologic framework of the study. The primary purpose of this research is to examine the impact of early phase urban design decisions on energy demand, supply, and UHI intensity in residential areas through the below six research questions:

Q1: How early decisions regarding the urban form at the block level affect the future residential buildings' operational (cooling, heating, lighting) energy demand?

Q2: How early decisions regarding the urban form at the block level affect the future residential buildings' active (PV Systems) solar energy potential?

Q3: How early decisions regarding the urban form at the block level affect the trade-offs between the buildings' energy demand and solar energy potential?

Q4: How early decisions regarding the urban form at the block level affect the future residential buildings areas' UHI intensity?

Q5: How UHI affect the buildings' cooling and heating energy demand?

Q6: How climate affect energy demand, solar energy potential, and UHI intensity?

In this study, a bottom-up, physics-based approach is used for energy modeling; evaluations are conducted through simulations. In simulations, hypothetical models that are designed parametrically are used.

The main reason for preferring Physics-based modeling in this study is that the study investigates the effects of design decisions. Because the main focus of physical models is individual end-uses and allows evaluating current technologies, this allows a detailed assessment of the correlations between energy demand and supply.

Another reason is that these models work independently of historical data. This independence provides a great deal of flexibility for a study evaluating the effects of design decisions, in which the evaluation is based on the comparison between design alternatives (Part 2.3.1.1).

As in many other studies in the literature (Part 2.1.2.2), hypothetical models are used to minimize the complexity and analyze in a more controlled manner.

Rather than using UBEM tools, simulations are performed in the Grasshopper environment. The main reason behind this is that with the help of plugins, Grasshopper allows getting answers to the research questions within the scope of the study in the same environment, and data exchanges within the plugins can be easily managed. To the best of found knowledge, there is currently no UBEM tool that can answer all these research questions, which means several tools need to be combined. As mentioned before in part 2.3.1.2, data exchange between programs can be problematic, and it can also lead to a waste of time. The second reason, very few UBEM tools allow a parametric approach. Since the study focuses on understanding the effects of design decisions rather than evaluating limited design alternatives in a defined area, the parametric approach is considered more suitable for this study, as it allows to create many design alternatives at the same time, effortlessly (Part 2.3.3).

This chapter consists of three parts. In the first part, the simulation flowchart is explained with its analysis steps. The second part explains which parameters are used, while in the third part, how the analyzes are made is explained.

3.1 Simulation Flowchart

Figure 3.1 shows the simulation flowchart, which allows answering the research questions. It was framed based on the workflows used in the previous studies (Fang, 2017; Ibrahim et al., 2021; Naboni et al., 2019; Natanian, 2020; J. Zhang, Xu, Shabunko, En, et al., 2019)

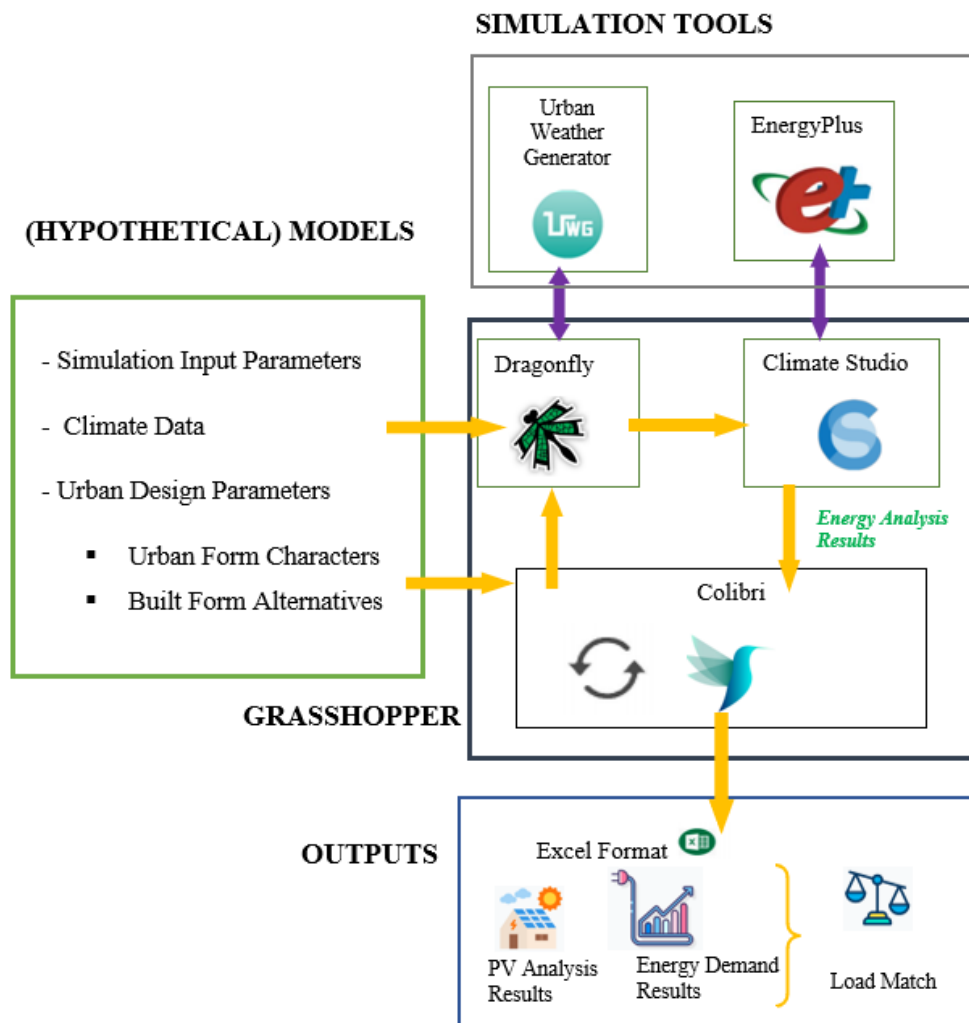


Figure 3.1. Simulation Flowchart of the Research

The simulation flowchart consists of three plugins: Dragonfly, Climate studio, and Colibri. Dragonfly is the plugin version of the Urban Weather Generator. As mentioned before, UWG was developed for accounting for the UHI effect. It modifies the meteorological data, which is generally acquired from outside urban areas to urban areas. Climate Studio is a plugin for Rhino, also works within the Grasshopper environment. It is developed for energy performance analysis, and daylight analysis relies on EnergyPlus¹⁹ and RADIANCE²⁰ simulation tools. Both of them are validated BEM (Building Energy Modeling) tools, which are also most of the UBEM tool's calculation basis. EnergyPlus is developed for building energy consumption and water use calculations, while RADIANCE is developed for lighting analysis and visualization. Colibri has two prominent features: iteration and aggregation. As an iterator, it provides an automatic transition between the values specified in the parameter so that the simulations can continue uninterrupted. It allows recording the data (in CSV format) obtained from each iteration when it works as an aggregator.

The analysis steps can be summarized as: The simulation flow starts with the input of the simulation parameters. Climate data is first transferred to Dragonfly. Dragonfly modifies these climate data into urban data via UWG. In other words, new data from Dragonfly are data created by considering the urban heat island effect of climate data. These modified data are transferred to the climate studio. Climate studio performs energy analysis by connecting to EnergyPlus. At the same time, radiation analysis also carried out through Climate Studio. The data obtained from Climate Studio is transferred to Colibri. Colibri is responsible for iteration and aggregation. It starts the following analysis, and the loop repeats until the iterations are finished. The results are received in CSV format via Colibri.

¹⁹ For more information refer to <https://energyplus.net/>

²⁰ For more information refer to www.radiance-online.org

3.2 Hypotetical Models

The simulation workflow described above can be applied with different input parameters and for different models, cases. Just as this study is adapted from other studies' workflows, this flowchart can also be rearranged, expanded, or narrowed according to research/projects aims.

In this study, the simulation workflow was customized in the context of Turkey. Hypothetical models were created according to the regulations in Turkey. This part explains how the hypothetical models were created and which parameters were used in the study. Just before starting this part, brief information about the building sector in Turkey is given.

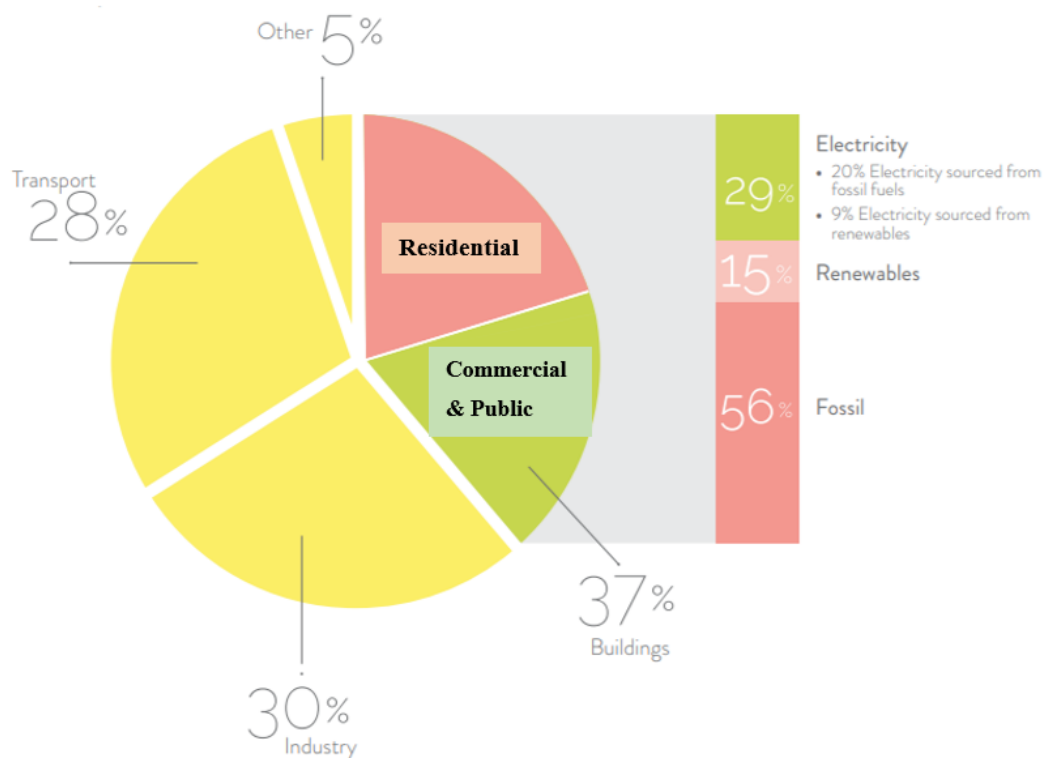


Figure 3.2. Distribution of final energy use in Turkey by sectors (Source: OECD/IEA, 2017 as cited in (MoEU (Ministry of Environment and Urbanization), 2018))

As seen in figure 3.2, the building sector is responsible for more than one-third of Turkey's total energy demand (OECD/ IEA. 2017 as cited in (MoEU (Ministry of Environment and Urbanization), 2018)).

In Turkey, where the rate of urbanization is high (two percent per year), the rate of new building stock increases around 4 percent annually (MoEU (Ministry of Environment and Urbanization), 2018). This rate is more than four times the average of European countries (Schimschar et al., 2016). If the construction rate continues this way, approximately a 65 percent increase is expected in the residential building stock by 2050 compared to 2015 (Schimschar et al., 2016) (Figure 3.3).

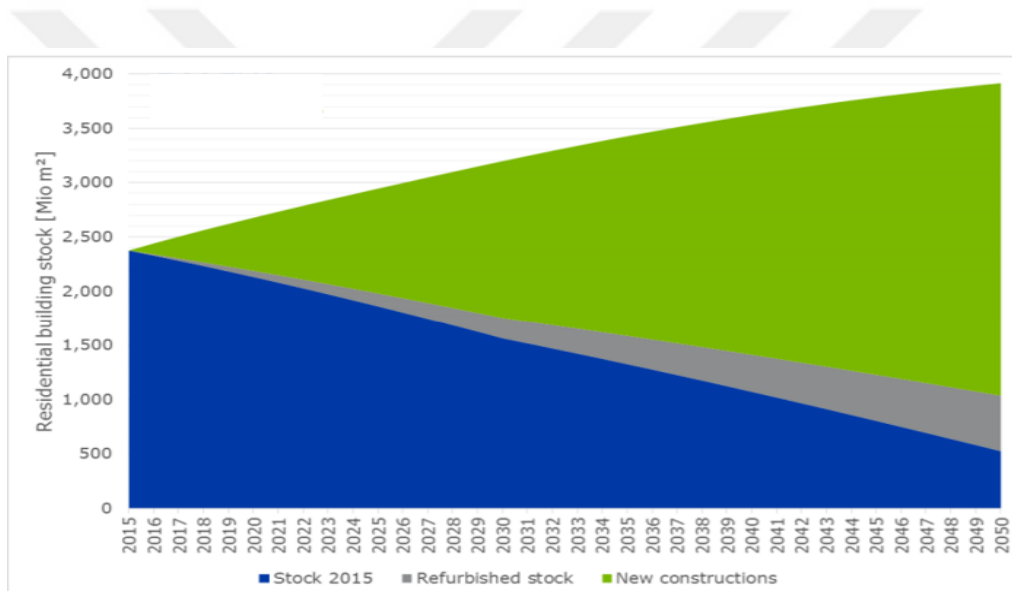


Figure 3.3. Expected change of residential building stock in Turkey (Source: (Schimschar et al., 2016))

Based on these ratios, how the building stocks are designed plays an essential role in achieving energy efficiency and climate change mitigation and adaptation for Turkey (MoEU (Ministry of Environment and Urbanization), 2018; Schimschar et al., 2016).

Hypothetical models were created following the Turkish regulations²¹. The hypothetical site area was designed to consist of nine building blocks in total. Each building block (90 m *90 m) consisted of four equal plot areas, where each plot area was measuring 45 m *45 m. Calculations were made for the building stock in the middle, taking into account the interaction of the surrounding buildings. In the regulation, building heights are limited according to street widths. Therefore, the street widths were modeled to vary according to the building heights.

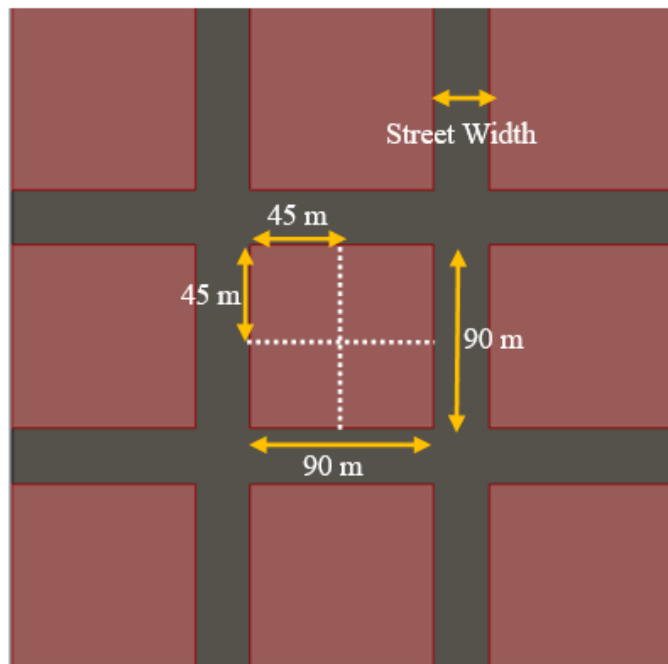


Figure 3.4. Hypothetical site area

²¹ “Planlı Alanlar İmar Yönetmeliği”:
<https://www.mevzuat.gov.tr/mevzuat?MevzuatNo=23722&MevzuatTur=7&MevzuatTertip=5>

3.2.1 Urban Design Parameters

3.2.1.1 Built Form Alternatives

Three representative built form alternatives were identified: Pavilion, Semi-street, and Semi-court. Setback distances from the street and distance between buildings were modeled in accordance with the regulations.

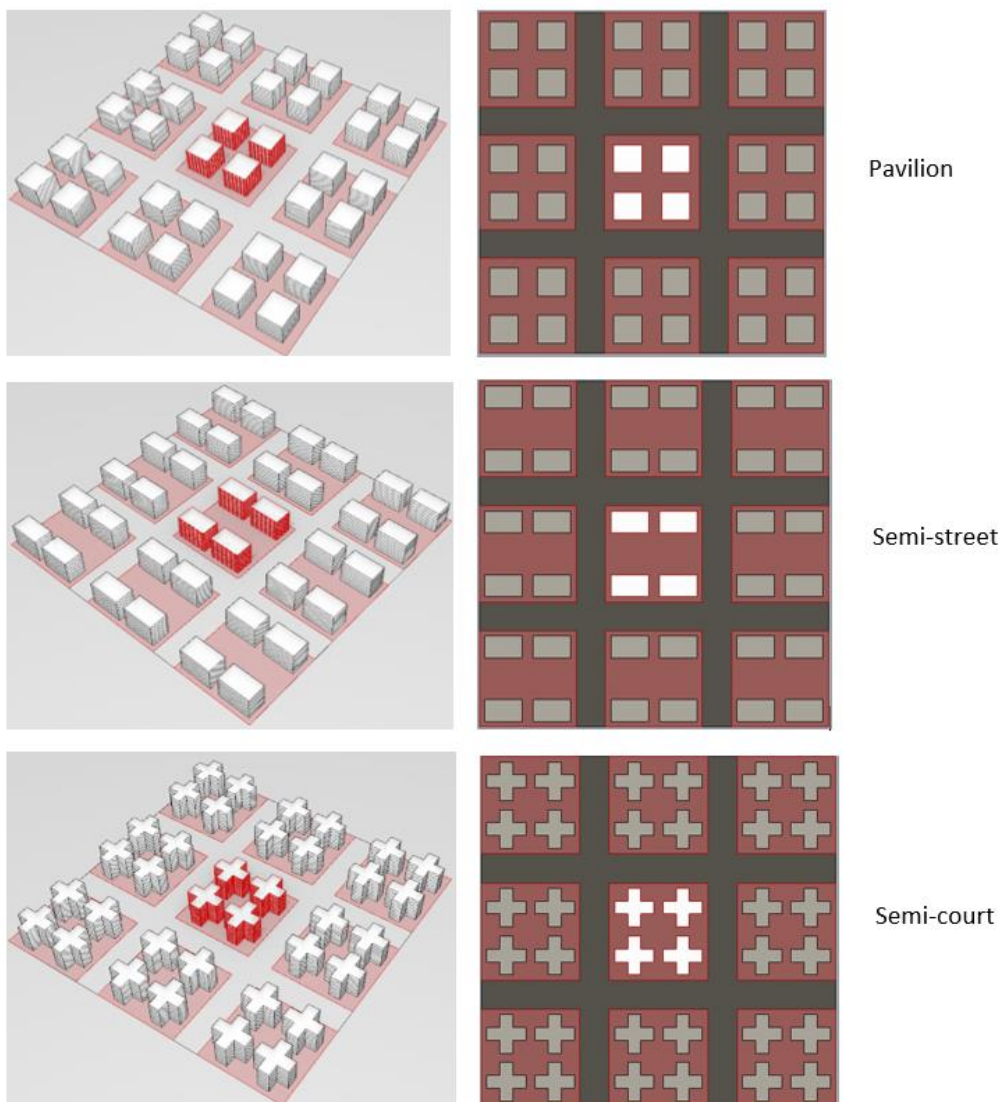


Figure 3.5. Identified built form alternatives

3.2.1.2 Urban Form Characters

In the literature section, urban form characters highly relevant in buildings' energy performance were discussed in detail under six categories: density, diversity, compactness, green areas, shading, and orientation. In this study, mutual shading was taken into account through the simulations; they adjusted to consider the interaction between buildings. Since the study's scope is limited to residential urban areas, diversity parameters were eliminated. Density and orientation were determined as parameters. Compactness parameters were discussed in terms of their correlation with density parameters.

For all built forms, the site coverage ratio was modeled to be constant and 35 percent. In other words, the footprint of the building in each plot area was equal and constant. In this case, the building block (island) **density** was controlled by the building height (or floor area ratio since it is the ratio of gross building floor area to built area: as building height increase, the floor area ratio also increase due to constant site coverage ratio). Floor heights were adjusted to be 3 m from floor to floor. Three different numbers of floors, 3, 6, and 9 (9, 18, and 27 m building heights), were used.

As mentioned before, the regulation restricts the building heights according to the street widths. In other words, maximum aspect ratios are controlled by the regulation. The street widths are modeled as 9, 18, and 27, within the regulation range for 3, 6, and 9 storey buildings.

All these built forms are shown at the bottom of Figure 3.6. As mentioned in the literature chapter using only one indicator to determine density may be deceptive. The spacemate diagram was developed to describe the relationship between urban form and density using four density indicators (Pont & Haupt, 2009). At the top of Figure 3.6, how these built forms are positioned in the spacemate diagram are also shown.

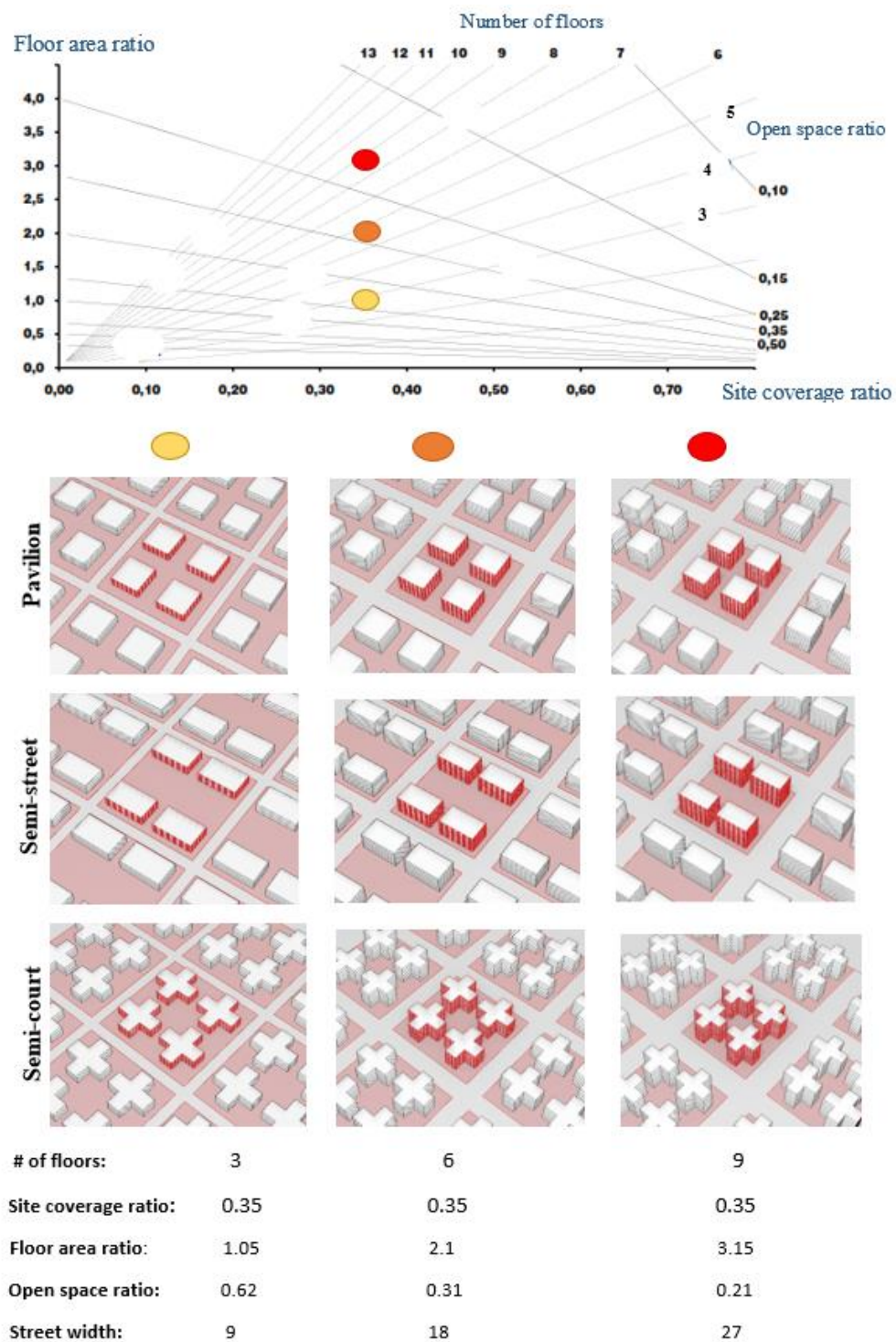


Figure 3.6. Built forms with varying densities and their positions in the spacemate diagram.

Surface-to-volume ratio (S/V) is a widely used indicator to quantify **compactness** (p. 49-50). As this ratio increases, compactness decreases. The below graph shows that identified built forms' surface-to-volume ratios decrease with the increase in floor area ratios. In short, for identified cases, as the density increases, the compactness also increases. Although this 3D indicator considers volume, this only quantifies building geometry compactness without site area considerations.

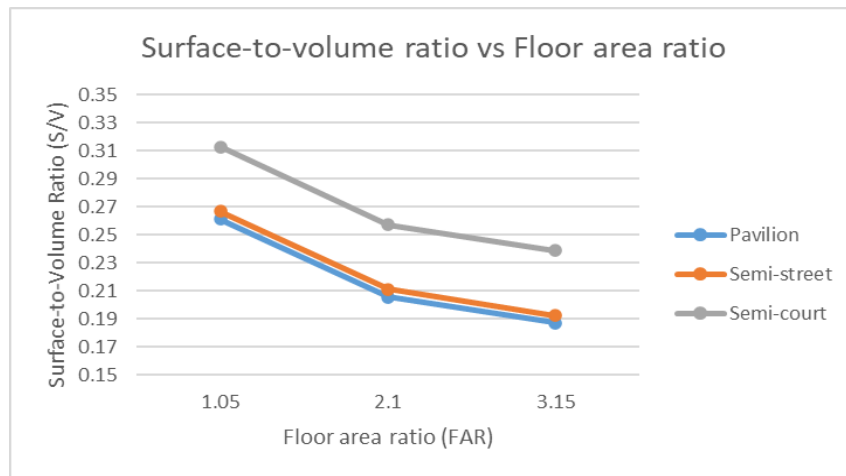


Figure 3.7. Relationship between S/V and FAR for the identified built forms

Another indicator for quantifying compactness is built compactness (p. 51). The below figure show the built compactness ratios of each built forms.

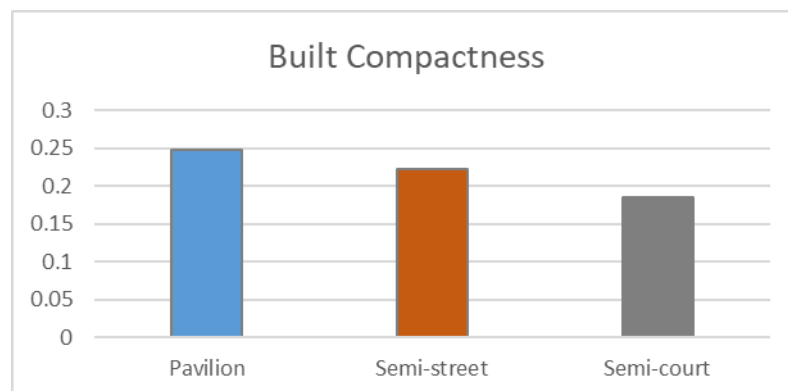


Figure 3.8. Built compactness ratios of the identified built forms

This 2D indicator only considers areas. Therefore FAR or building height do not change the built compactness. According to the graph, pavilion is the most compact form. The differences between the ratios are too small, as is expected, since the formula is directly proportional to site coverage ratio, which is fixed in the study.

The simulations were run for three different **orientations** of the site area, 0, 22.5, and 45 degrees, with deviations clockwise from true north (Figure 3.9).

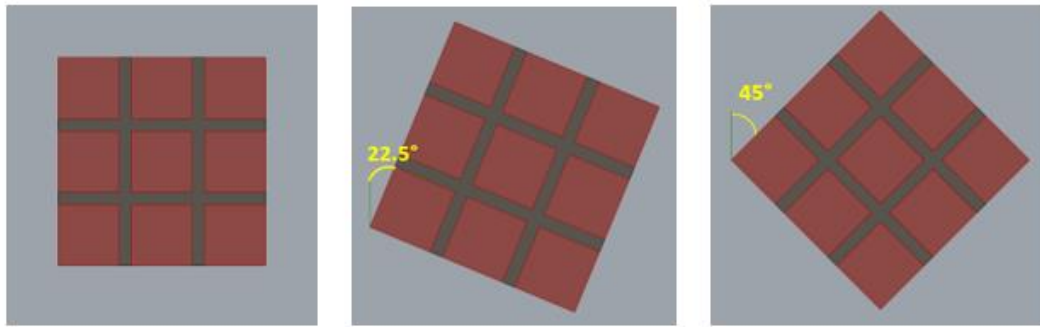


Figure 3.9. Three different orientations of the site area

3.2.2 Climate Data

The Köppen-Geiger is a widely used climate classification system that characterizes climates under five main types: “A: equatorial, B: arid, C: warm temperate, D: snow, and E: polar” (Kottek et al., 2006). There are three main climate types (B, C, D) in Turkey (Figure 3.10); when these main climate types are divided into subcategories, ten climate types are observed (Öztürk et al., 2017).

In this study, the climate data of the cities of İzmir (C), Konya (B), and Van (D), which represent Turkey's three main climate classes, were used. These three cities are at the same latitude. The reason for this choice was to keep the energy supply potential almost constant to see the effect of solely different climates on the energy balance.

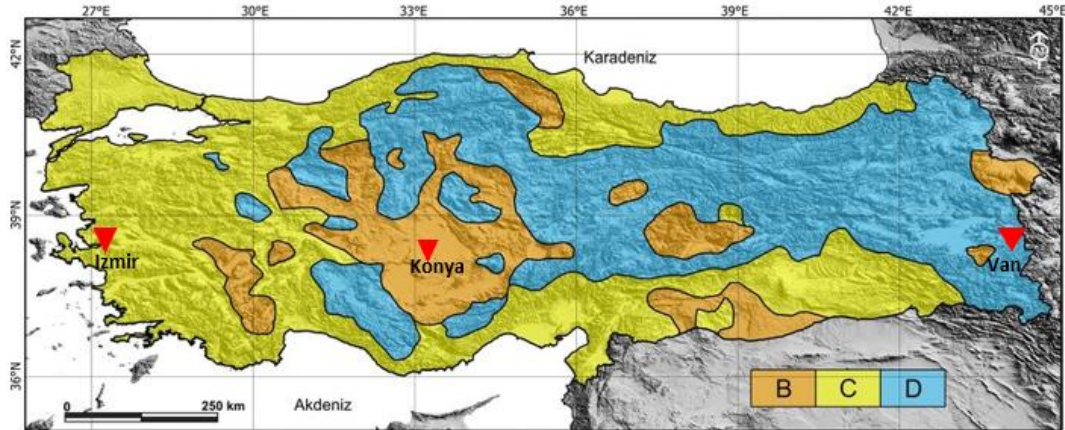


Figure 3.10. Major Climate Types in Turkey (Öztürk et al., 2017)

According to the sub-classification, the climate class is Csa in İzmir, BSk in Konya, and Dsb in Van. İzmir has a typical Mediterranean climate with warm winters and hot summers. Konya belongs to climate class B with the least rainfall; a semi-arid climate is observed with cold winters and dry summers. Summers in Van are warm; cold winters are typical in this D-class city (Öztürk et al., 2017).

For simulations, typical meteorological year data of these three cities were used in EnergyPlus weather format (epw), which contains hourly data. The data, measured from rural parts of these cities, were obtained from “Climate.OneBuilding.Org,”²², a website that provides climate data in various formats for performance analysis of buildings.

In evaluations, both these raw data and modified data through Dragonfly were used to consider UHI effect.

The below table summarizes all the parameters that are used in the study.

²² <http://climate.onebuilding.org/default.html>

Table 3.1 Parameters performed in the Simulation Flowchart

		<i>Parameters</i>	<i>Iterations</i>
<i>Urban Design</i>	Built Form	Pavilion ; Semi-street ; Semi-court	3
	Alternatives		
	Urban Form	Density-FAR: 1.05 ; 2.1 ; 3.15	3
	Characters	Orientation: 0 ° ; 22.5° ; 45°	3
<i>Climate</i>	Class (type)	Izmir (C) ; Konya (B) ; Van (D)	3
	Location	Rural (raw) ; Urban (modified)	2

Total: 162

3.3 Analysis

3.3.1 Energy Demand Analysis

Energy analyzes were performed for operational (heating, cooling, lighting, equipment, and hot water usage) demand. As mentioned before, these analyzes were made only for the building stock (90m *90m) in the middle.

Since this study was designed to be as generic as possible, the models were simplified instead of divided into zones in detail (e.g., kitchen, bedroom, living room) in energy demand analysis. Martin et al. investigated the three different modeling techniques' impacts on energy performance evaluation results by comparing the detailed model with simplified models for an office building in Singapore (Figure 3.11). The model that gave the closest results with the detailed model was the model divided into floors (Martin et al., 2017).

Following this study, the models were divided into floors for energy demand evaluations (Figure 3.12).

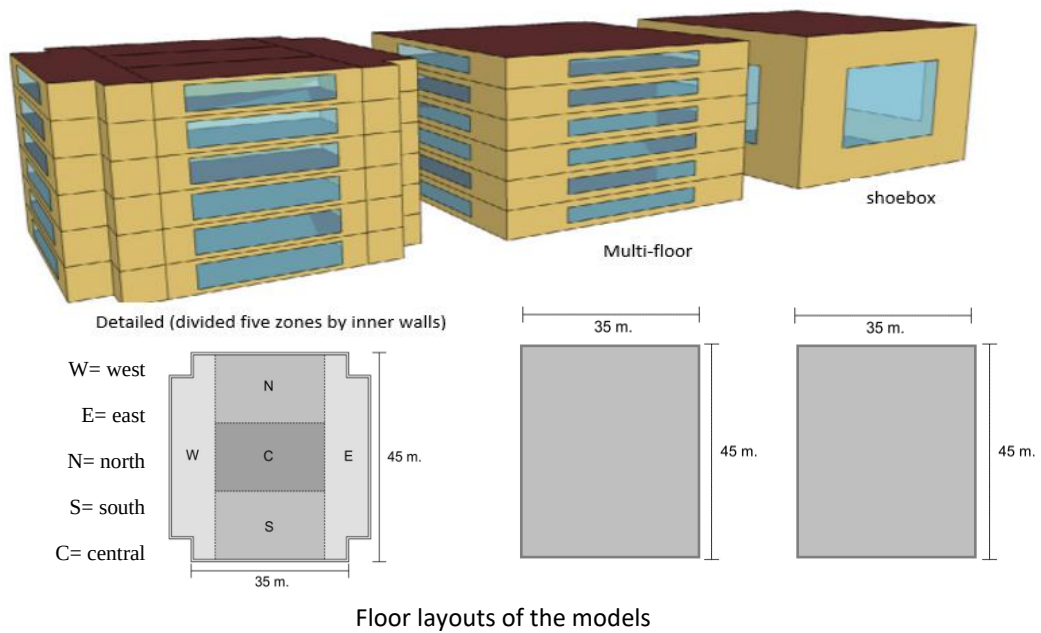


Figure 3.11. Detailed and simplified models (Source: (Martin et al., 2017))

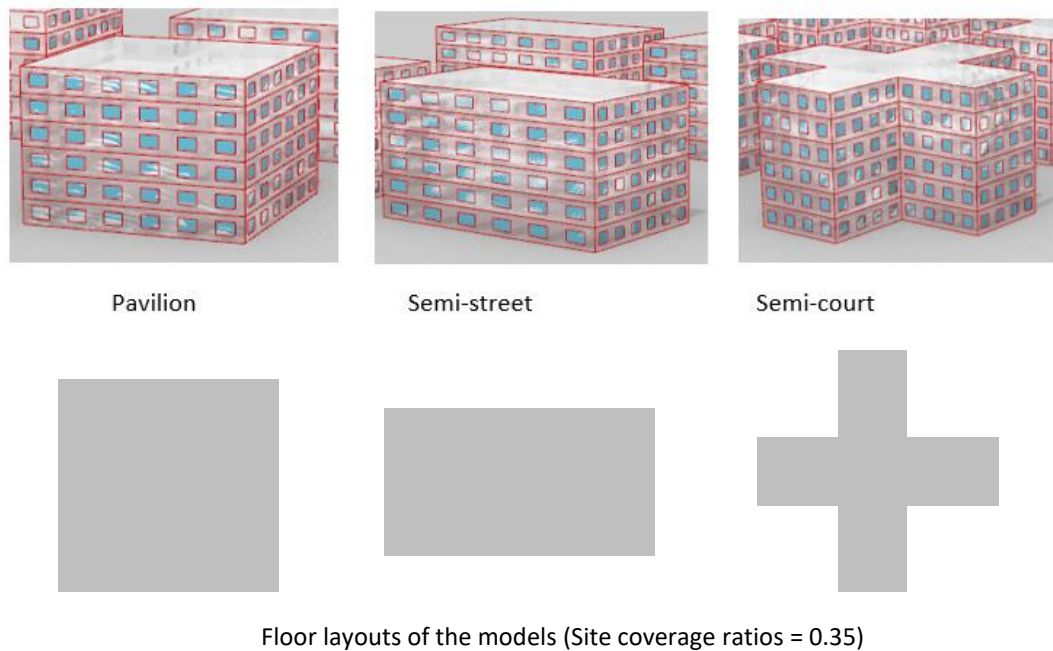


Figure 3.12. Representation of simplified multi-floor models used in this study

The window-to-wall ratios were kept constant, 25 percent in all facades.

The U-value is a measure of how much heat the material conducts. Bigger values mean poorer material insulation. For the simulations, these values were determined based on the "TS 825 Thermal insulation requirements for buildings" (TSI, 2013). The standard defined five climates (thermal) zones, and U-values requirements change according to these zones (Table 3.2).

Table 3.2 Maximum U-values (TSI, 2013)

Zones	Wall (W/m^2K)	Roof (W/m^2K)	Ground Floor (W/m^2K)	Window (W/m^2K)
1 (<i>Izmir</i>)	0.66	0.43	0.66	1.8
2	0.57	0.38	0.57	1.8
3 (<i>Konya</i>)	0.48	0.28	0.43	1.8
4 (<i>Van</i>)	0.38	0.23	0.38	1.8
5	0.36	0.21	0.36	1.8

Illuminance can be briefly defined as the amount of the luminous flux falling on a unit surface area. Illuminating Engineering Society (IES) 's recommendations, which change according to the building's intended use and the type of activity, were used for deciding the targeted illuminance value (IESNA, 2011 as cited in Fang, 2017). The value was chosen as general use in residential buildings for lighting demand calculations.

The other simulation input parameters were determined based on the previous studies conducted in Turkey's case e.g., (Ashrafian, 2016; Esiyok, 2006; Mangan et al., 2020; Sağlam et al., 2016)

Table 3.3 summarizes the simulation input parameters used in the study for buildings' operational energy demand analysis.

Table 3.3 Simulation input parameters used for energy demand analysis

	Setting Parameter		Value		
Loads	People	People density	0.04 p / m ²		
		Metabolic rate	1.2		
	Equipment	Equipment power density	4 W / m ²		
		Lighting power density	4 W / m ²		
		Illuminance target (lux)	100		
HVAC	Heating setpoint		20°		
	Cooling setpoint		26°		
	Heating COP (coefficient of performance)		3		
	Cooling COP (coefficient of performance)		3		
	Infiltration		1 ACH		
Hot Water	Peak Flow & Hot water COP		1.667 & 1		
	Supply & Main temperatures		60 ° & 10°		
			Izmir	Konya	Van
Material	U-wall		0.66	0.48	0.38 W/ m ² K
	U-roof		0.43	0.28	0.23 W/ m ² K
	U-ground floor		0.66	0.43	0.38 W/ m ² K
	U-window		1.8	1.8	1.8 W/ m ² K

The HVAC schedule was set to run all day. The occupancy and equipment schedules were selected from the Climate Studio's library. The lights availability plan was created based on previous studies, and the dimming type was chosen as continuous, which means the lighting system is set to be turned off when it is not needed, depending on the daylight. The schedules are shown in Figure 3.13.

In the simulations, energy demand analyzes were calculated as total annual kWh and monthly kWh. Energy use intensity (EUI) values were also calculated. Energy use intensity is obtained by dividing the total energy demand of the building by the total floor area of the building; in other words, it determines the energy need per square meter. EUI is frequently used in energy performance studies; it allows comparison between design alternatives with different dimensions (Olofsson et al., 2004).

Linear regression analyzes were also carried out, following the strategy of Ibrahim et al., to examine both the relationship between density and energy demand; and the relationship between orientation and energy demand (Ibrahim et al., 2021).

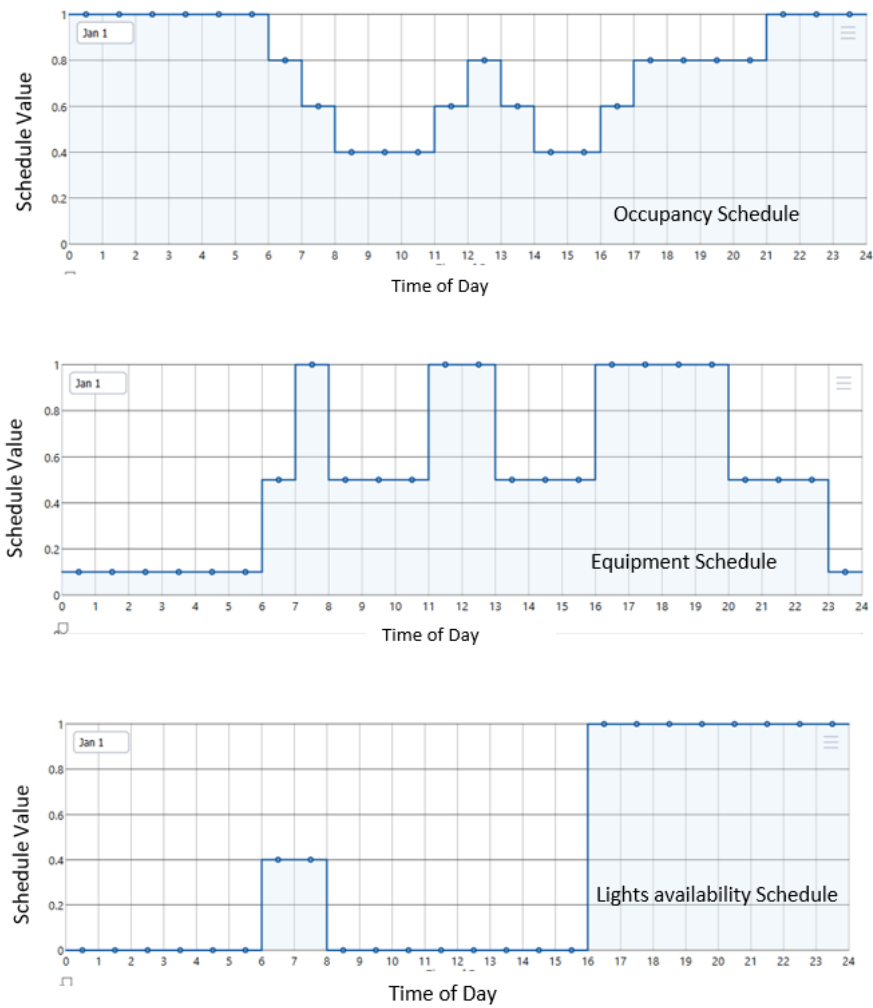


Figure 3.13. Schedules used in energy consumption calculations

3.3.2 Energy Supply (PV) Analysis

Solar photovoltaics (PV) panels convert sunlight into electrical energy. PV cell technologies can be roughly divided into three groups, of which Crystalline silicon-based PV is the most widely used one (for details see (IRENA, 2016)). PV systems

can work either on-grid or off-grid (Figure 3.14), and the general working principle of PV systems²³ is the same.

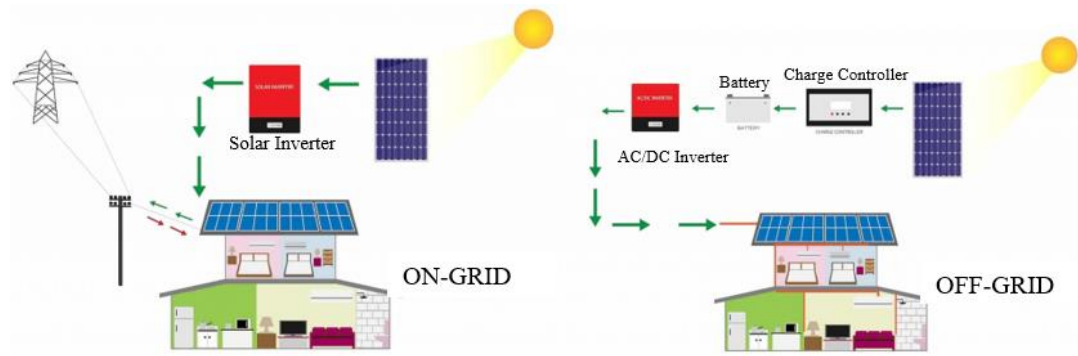


Figure 3.14. On-grid and Off-grid PV systems (Source: Green Coast²⁴, 2020)

There has been a remarkable decrease in PV module prices in the last ten years, and these declines in prices are expected to continue. Price decreases of up to 95 percent have been experienced in crystal silicon PV modules. Although it depends on the market, up to an 85 percent decrease was observed in the cost of installing the PV system on residential roofs (IRENA, 2020). Therefore, PV systems are no longer as costly as thought.

The amount of radiation that the PV module is exposed to is an essential factor in energy production. In PV energy integration studies, researchers generally set a specific radiation value limit, and these limit values are generally different for facades and roofs. For example, Compagnon, had set a limit of 800 kWh/m² for facades and 1000 kWh/m² for roofs (Compagnon, 2004). Natanian et al. also used these limit values (Natanian, Aleksandrowicz, et al., 2019b). Kanters and Wall defined the limits by giving certain intervals instead of setting a single limit value.

²³ For more information refer to: <http://gunam.metu.edu.tr/solar-tech/pv-working-principles/>

²⁴ Retrieved from <https://greencoast.org/on-grid-vs-off-grid-solar-systems/>

The lowest limit values were 650 kWh/m² for facades and 800 kWh/m² for roofs (Kanters & Wall, 2014).

In light of these studies, the annual radiation limit values were 800 kWh/m² for facades and 1000 kWh/m² for roofs.

Following Natanian et al.'s strategy, an annual radiation analysis was carried out to select the surfaces that provide these boundaries. Roofs and facades whose annual average limit values are exceeded were selected for PV analysis (Natanian, Aleksandrowicz, et al., 2019b). In the simulations, PV panels were adjusted to cover 80 percent of these selected surfaces (On the façades, only the walls were selected and adjusted to cover 80 percent of them). The efficiency of PV panels was chosen as 15 percent. (The average energy efficiency of crystalline silicon modules is around twenty percent as of 2020, (IRENA, 2020)). The analysis results were obtained as annual total energy production in kWh.

Linear regression analyzes were also carried out, following the strategy of Ibrahim et al., to examine both the relationship between density and energy supply potential; and the relationship between orientation and energy supply potential (Ibrahim et al., 2021).

3.3.3 Load Matching

Load matching serves to establish a relationship between the energy produced and the energy consumed. In other words, load matching shows how much the generated energy contributes to the energy need. For quantifying the matching amount, there are various load math indexes, from detailed to general ones (For details, see Salom et al., 2014).

In this study, load matching was used to discuss trade-offs between energy supply and demand. Following Kanters and Wall, load matching was calculated annually- without considering energy storage or losses- by dividing the total amount of generated solar energy by the total energy need (Kanters & Wall, 2014).

3.3.4 UHI Analysis

As mentioned before, the urban heat island analyzes were made via Dragonfly. The difference between raw data and modified data was evaluated as heat island intensity. In order to understand the effect of the urban heat island on the energy demand (p.76), the simulation flowchart shown in Figure 3.1 (p. 81) was run in two ways. In the first one, energy analyzes were performed with the modified data, and in the second one with raw data by deactivating Dragonfly.

Dragonfly needs some simulation input parameters at building and city scales to modify the epw file to the urban microclimate. The following table contains the input parameters used for the simulations. The determination of input parameters was set with the help of previous studies (Aiko et al., 2015; Bueno et al., 2013; Nakano, 2015; Natanian, 2020; Sailor, 2011).

Table 3.4 Simulation input parameters used for UHI analysis

Building program		Midrise apartment		
Construction Period		New construction		
Sensible anthropogenic heat flux		8 W/m ²		
Green coverage ratio (trees /grass)		0		
Buildings' waste heat ratio due to air conditioning		0.5		
Albedo roof /wall / ground		0.2 / 0.3 / 0.1		
Window-to-wall ratio		0.25		
Windows' solar heat gain coefficient (SHGC)		0.5		
*automatically calculated by Dragonfly		3-storey	6-storey	9-storey
Average building height*		9 m	18 m	27 m
Footprint density (total site area density including streets)*		0.31	0.27	0.24
Facede-to-site ratio*	Pavilion	0.42	0.74	0.99
	Semi-street	0.43	0.77	1.02
	Semi-court	0.56	0.99	1.32

CHAPTER 4

RESULTS & DISCUSSION

This part presents the simulation results and discusses the research questions based on the simulation findings.

Energy demand-supply analysis results were obtained in kWh (kilowatt-hour) or kWh/m² (kilowatt-hour per m²) units. Kilowatt-hour is “a measure of electricity defined as a unit of work or energy, measured as 1 kilowatt (1,000watts) of power expended for 1 hour.”²⁵ The figure below shows the various activities corresponding to 1 kWh of electricity use.



Figure 4.1. Example electricity uses corresponding to 1 kWh ²⁶

²⁵ <https://www.eia.gov/tools/glossary/index.php?id=K#kwhour>

²⁶ <https://www.directenergyregulatedservices.com/learn/what-is-a-kwh>

4.1 How early decisions regarding the urban form at the block level affect the future residential buildings' operational energy demand?

4.1.1 Built Form and Energy Demand ²⁷

Figure 4.2 (top) shows yearly total energy demand in kWh. These consists of heating, cooling, lighting, equipment, and hot water demand. The results indicated that Pavilion performed the best while Semi-court was the worst at the same FAR and SCR (site coverage ratio was fixed and 0.35 in this study)- although the differences were relatively low. The differences between energy demands between Pavilion and Semi-court shape were ranged between 3-4%.

This difference is compatible with the built compactness ratios and surface-to-volume ratios of the built forms; Pavilion was the most compact form while Semi-court was the least (p. 89). Since the difference between these rates was not much, the difference between the energy demands may not have been high. Also, as stated before, the built compactness ratio is directly proportional to the site coverage ratio. Therefore, since the site coverage ratio was constant for all built forms, the energy demands may have been close in the same floor area ratios.

Figure 4.2 (bottom) also shows yearly energy use intensity (p.96), corresponding to energy demand per m². In design alternatives where floor area ratios are the same, Pavilion and Semi- Street had almost the same EUI, while semi-court had slightly higher EUI values. The surface-to-volume vs. built-form graph can explain this difference (p.89): The Pavilion and Semi-Street graphics were almost overlapped, while the court graphic had higher surface-to-volume values.

²⁷ Here, to solely compare the impact of the built form, comparisons were made for the same location, same orientation, same FAR but different built forms. E.g., Izmir, 0-degree orientation, 3-storey Pavilion, semi-street, and semi-court alternatives were compared within themselves.



Figure 4.2. Total Energy demand (kWh/a) (top) and EUI (kWh/m²/a) (bottom)

Hot water demand and equipment demand were the same for all design alternatives, as expected. Annual energy use intensities were 6.78 and 18.54 kWh/m², respectively. The figures below show heating, cooling, and lighting energy use intensities.

The differences between heating EUI were ranged between 7-11%; Semi-court EUI's were the highest, which means compared to Pavilion and Semi-street with the same floor area, the heating demand per m² of Semi-courts were the highest (Figure 4.3).

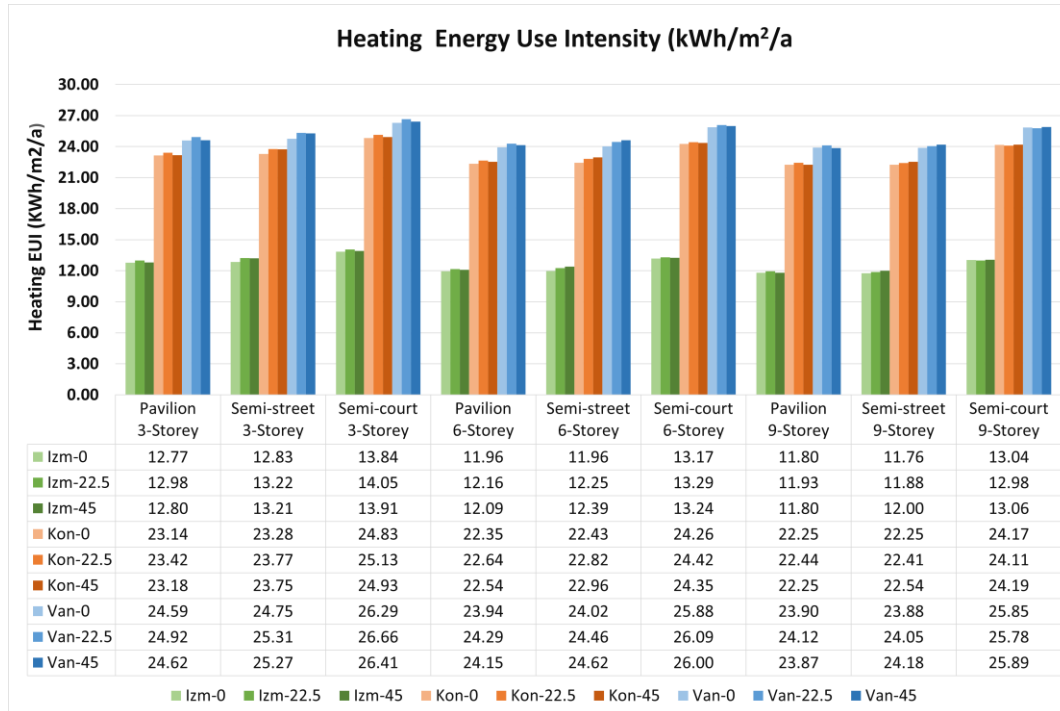


Figure 4.3. Annual Heating EUI (kWh/m²)

The built form was most effective on the cooling EUI. For the cooling need, the semi-court form again showed the worst performance. Unlike other results, the semi-street form achieved the best energy performance results here. The difference in the cooling EUI values between the alternatives of these two forms with the same FAR varied between 7-26 % (Figure 4.4, top).

The lighting EUI values were very close among the alternatives of the built forms with the same floor area. The percentage of change between values were around 4% at most (Figure 4.4, bottom). In the simulations, the illumination target for lighting was set the same. But the dimming type is set to continuous; that is, the lighting

system was turned off in cases where it is not needed depending on daylight. The differences arising from the need for lighting here may be due to the differences in daylight availability.



Figure 4.4. Annual cooling EUI (top) and lighting EUI (bottom) (kWh/m²)

4.1.2 Density and Energy Demand

In this study, density was controlled by building height (or FAR since site coverage ratio of the building blocks are identical p.87-88).

A simple linear regression analysis was performed to foresee how the annual total energy demand changed with floor height. The R^2 value of this significant regression equation ($F(1,79) = 5040.37$, $p < 0.0001$) was found to be 0.984. Moreover, the estimated annual energy demand equation was $6841.196 + 170322.488 \times (\text{the number of floors})$, which means the total energy demand increased by 170322.488 kWh for each added floor (Figure 4.5, top left).

On the other hand, the same analysis was performed to predict how the annual energy use intensity changed with floor height. The equation found did not give a statistically significant result with the R^2 value of 0.0057 (Figure 4.5, top-right).

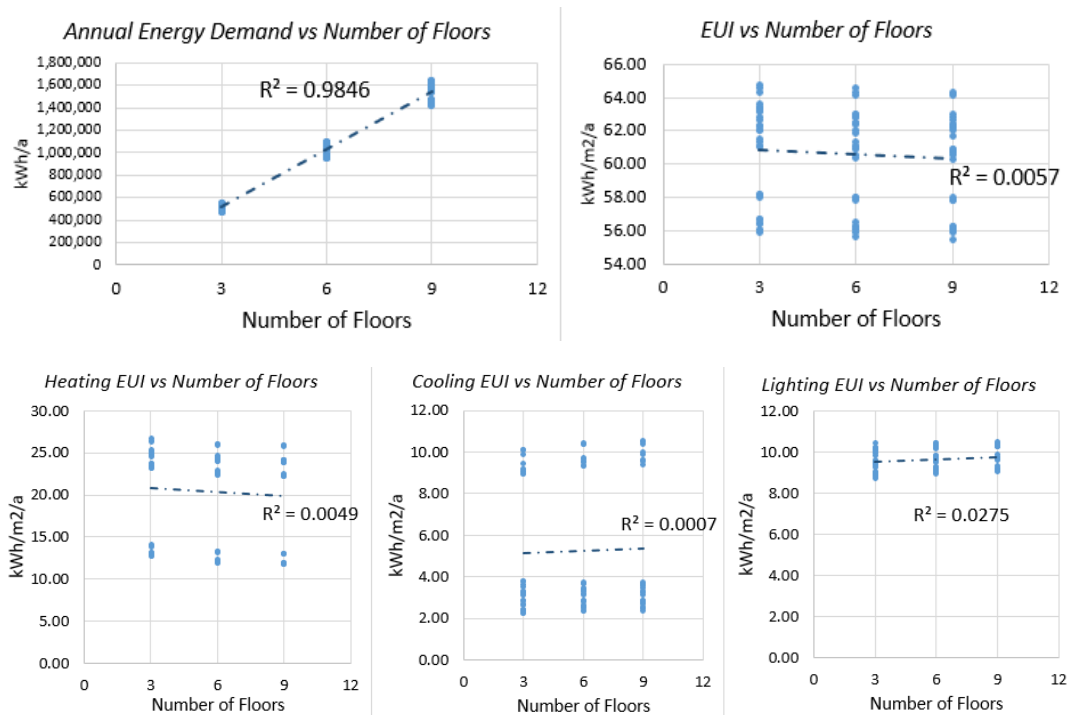


Figure 4.5. Relationship between number of floors and annual energy demand/ Total EUI/ Heating EUI/ Cooling EUI/ Lighting EUI

In addition, regression analyzes were performed separately for heating, cooling, and lighting. Analysis results were statistically insignificant, just like the total EUI (Figure 4.5-bottom).

The figure below shows EUI values for varying building heights. To solely consider density and EUI relationship, comparisons were made for the same location, same orientation, same built forms, but different FAR. For example, Izmir, 0-degree orientation, 3/6/9-storey Pavilion alternatives were compared within themselves. Most of the values' differences were almost the same. The maximum difference between EUI values was seen as 2%.

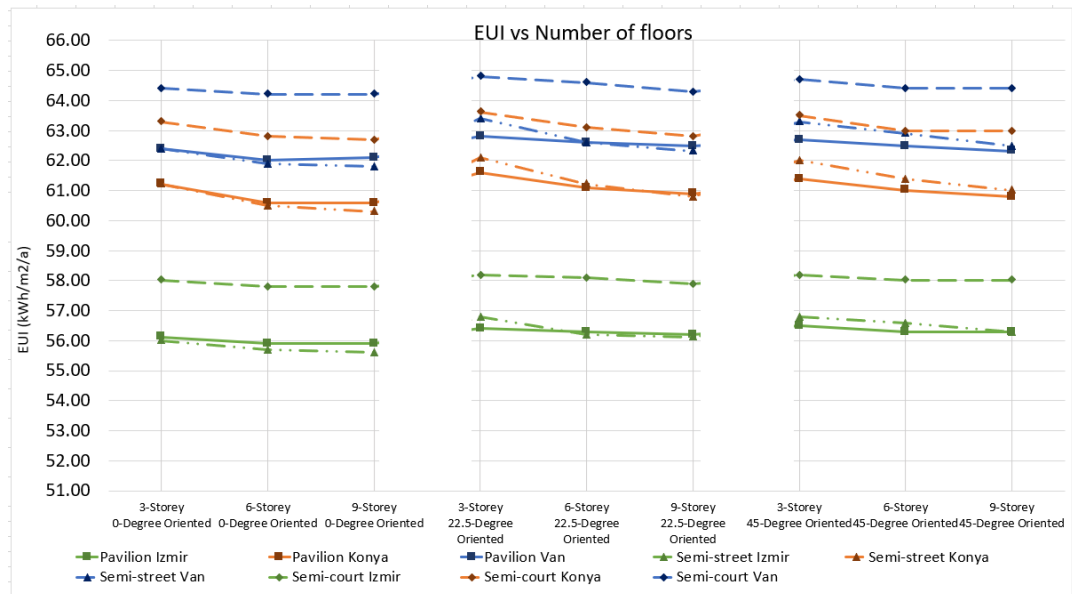


Figure 4.6. EUI values for varying building heights

4.1.3 Orientation and Energy Demand

Three different site orientations were used, with deviation angles of 0°, 22.5°, and 45° (p.90).

A series of linear regression analyses were performed to see the relationship between orientation and energy demand; the first was annual total energy demand vs. orientation, and the second was EUI vs. orientation. Furthermore, the relationship between orientation and heating/ cooling/lighting EUI values was analyzed separately. Results were not statistically significant (Figure 4.7).

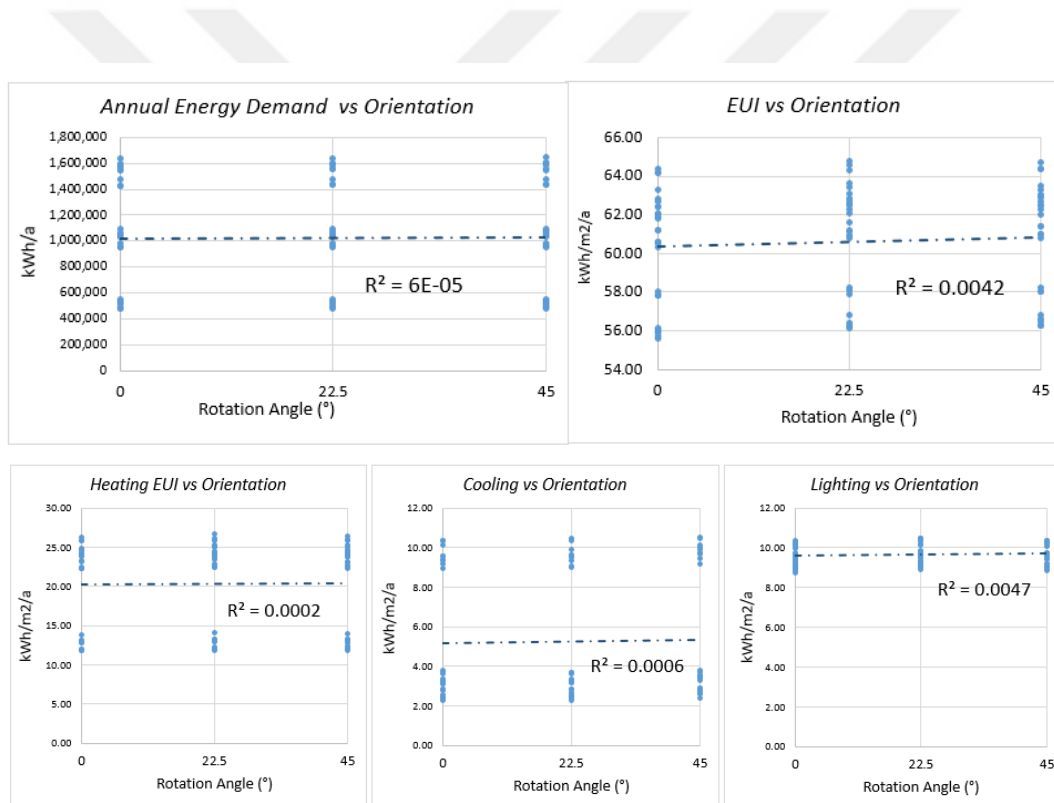


Figure 4.7. Relationship between orientation and annual energy demand/ Total EUI/ Heating EUI/ Cooling EUI/ Lighting EUI

Figure 4.8 shows EUI values for varying site orientation. To solely consider orientation and EUI relationship, comparisons were made for the same location, same number of floors, same built forms, but different orientations. For example, Izmir, 3-storey, Pavilion 0° /22.5° / 45° alternatives were compared within themselves. The maximum difference between EUI values was 2%.

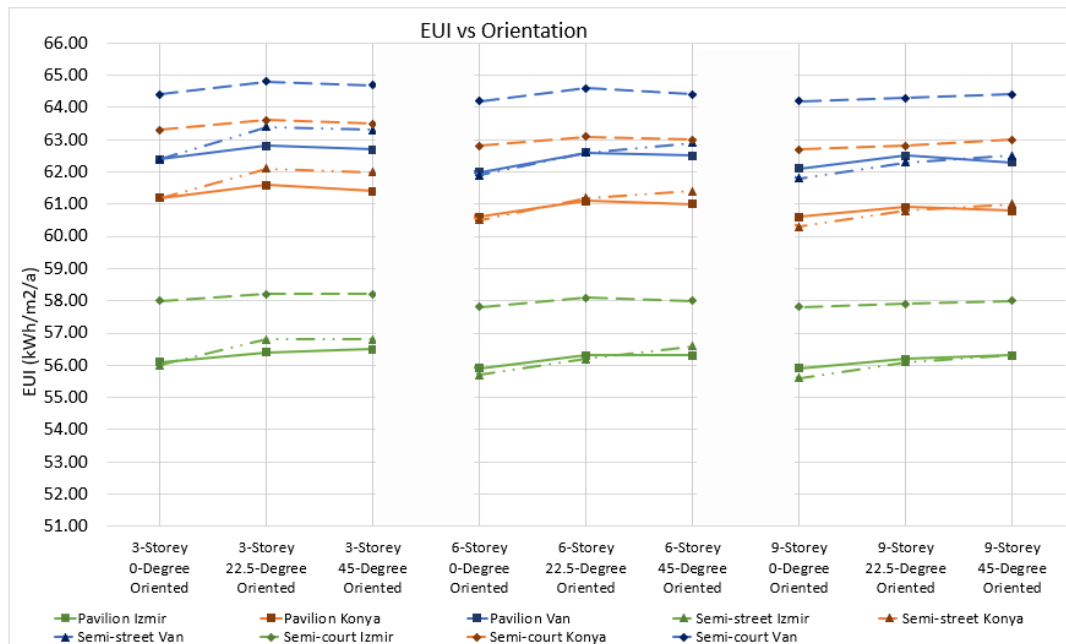


Figure 4.8. EUI values for varying site orientation

4.2 How early decisions regarding the urban form at the block level affect the future residential buildings' active (PV Systems) solar energy potential?

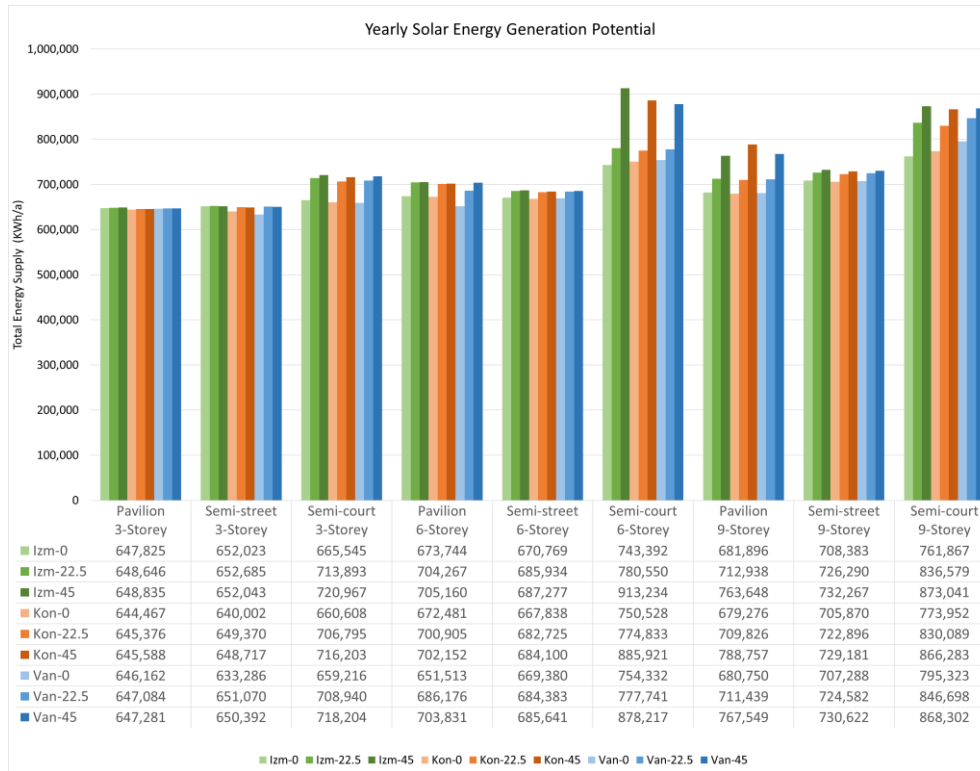


Figure 4.9. Solar energy generation Potential (kWh/a)

4.2.1 Built Form and Solar Energy Generation Potential²⁸

Figure 4.9 shows annual solar energy generation potential from Photovoltaic (PV systems) (top).

According to the simulation results, Semi-court, which had the smallest compactness ratio, had the highest production potential. Pavilion's and Semi-street's potentials

²⁸ Here, to solely compare the impact of the built form, comparisons were made for the same location, same orientation, same FAR but different built forms. E.g., Izmir, 0-degree orientation, 3-storey Pavilion, semi-street, and semi-court alternatives were compared within themselves.

were similar; in half of the cases, semi-street and in others, Pavilion was advantageous in solar energy production potential. Semi-court had the potential to produce 3% to 33% more energy than Pavilion and Semi-street. When only the potentials of Semi-street and Pavilion forms were compared, the difference varies between 0 to 8 %.

However, there is another point that needs to be mentioned here. As stated on pages 98-99, limit radiation values were determined; for roofs (1000 kWh/m^2) and facades (800 kWh/m^2). Since the heights of the buildings in the site area were the same, facades rather than roofs were affected by mutual shading. The reason why Semi-street showed less production potential than the Pavilion in some cases might have been if some of its facades fall below the limit values with the effect of mutual shading.

4.2.2 Density and Solar Energy Generation Potential

A simple linear regression analysis was performed to foresee how the annual solar energy potential changed with floor height. The equation found did not give a statistically significant result with the R^2 value of 0.319 (Figure 4.10, left).

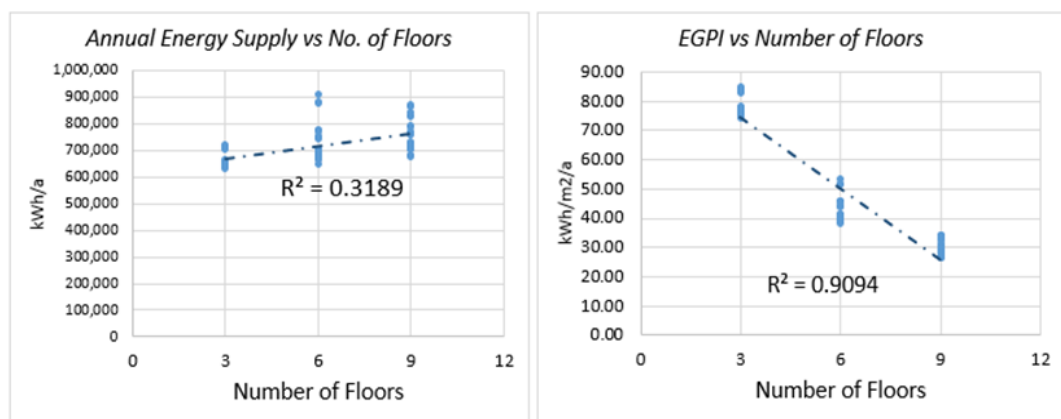


Figure 4.10. Relationship between density and annual energy supply potential/energy generation potential intensity

In addition, based on the energy use intensity indicator, energy generation potential intensity (EGPI), the energy production potential corresponding to m^2 , was calculated (Figure 4.11). The same analysis was performed to predict how the annual solar energy generation potential intensity changed with floor height. The R^2 value of this significant regression equation ($F(1,79) = 792.56$, $p < 0.0001$) was found to be 0.909. Moreover, the estimated annual energy demand equation was $98.511 - 8.07 \times (\text{the number of floors})$, which means the total energy generation potential intensity decreased by 8.07 kWh/m^2 for each added floor (Figure 4.10, right).

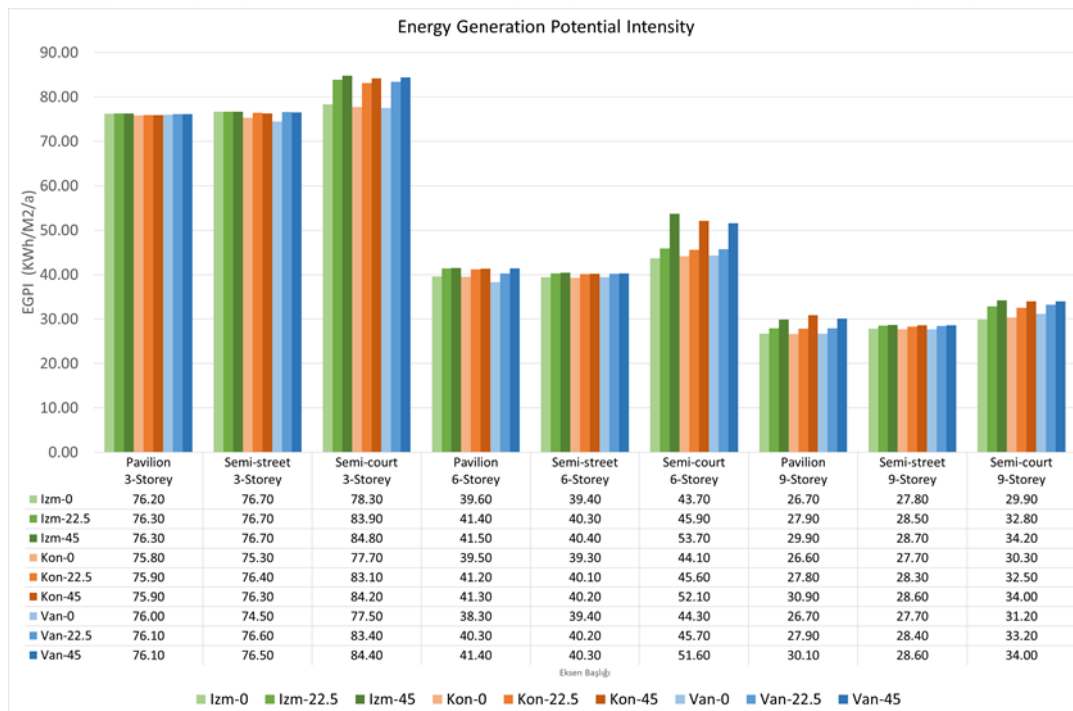


Figure 4.11. Energy Generation Potential Intensity ($\text{kWh/m}^2/\text{a}$)

As building height increased, the energy production potential per square meter decreased. The energy production potential per square meter between 3 floors and 9 floors decreased by 60-65 percent.

4.2.3 Orientation and Solar Energy Generation Potential

Linear regression analyses were not statistically significant for the relationship between energy supply potential and orientation (Figure 4.12).

As seen in Figure 4.9 (p.110), the relationship between orientation and solar energy potential was more evident in 6 and 9-layer design alternatives. Except for Semi-court, the energy potential change due to orientation change was smallest in 3-storey forms. Depending on the orientation, the highest rate of change in solar energy potential was 23 percent. However, the point that should not be overlooked was the radiation analysis limits set for PV analysis. The reason for this sudden change may be that the façade exceeded the limit values due to the orientation difference and was selected for PV analysis.

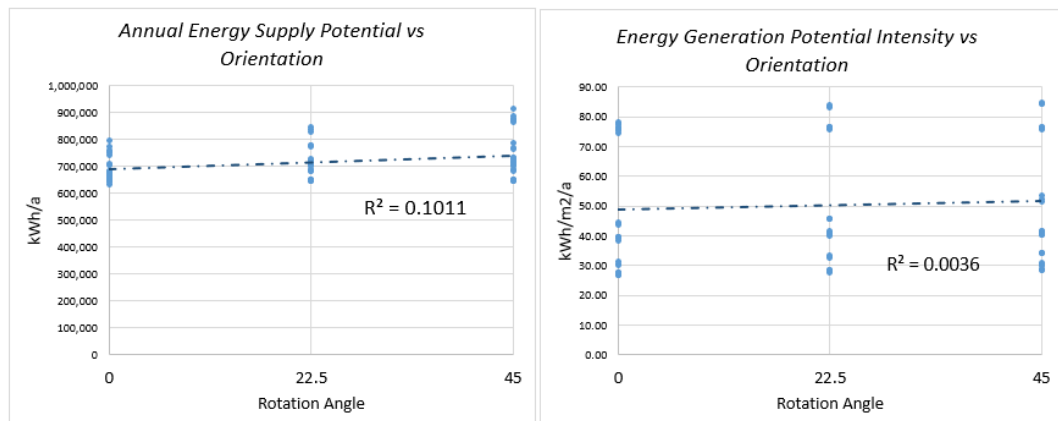


Figure 4.12. The relationship between Orientation and Annual Energy Supply Potential / Energy generation potential intensity

4.3 How early decisions regarding the urban form at the block level affect the trade-offs between the buildings' energy demand and solar energy potential?

Load matching gives an idea about how much the energy production potential contributes to meeting the energy need (p.98); here, calculated by dividing the annual total amount of solar energy potential by annual total energy demand.

Figure 4.12 shows the results of load matching between solar energy generation potential and energy demand.

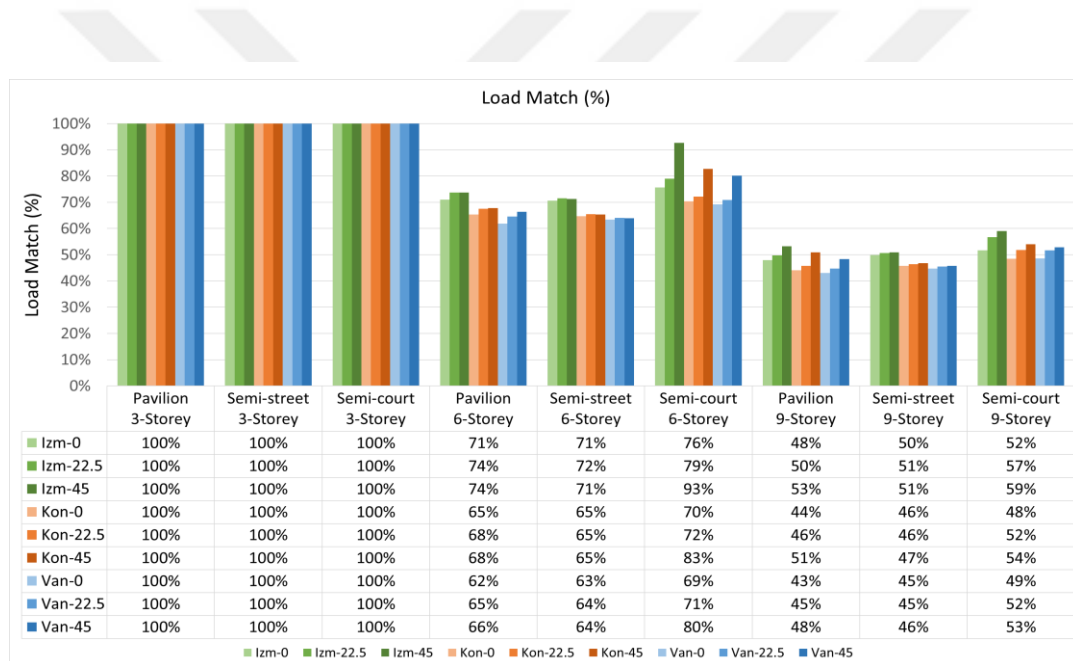


Figure 4.13. Load Match between energy consumption & generation potential

4.3.1 Built form and load matching

While semi-court was the most disadvantaged in energy demand analysis, it was the most advantageous in energy supply potentials. Considering the load matching results, semi-court gave the best results among these three forms. The difference was most evident in the 6-storey design alternatives. While the 6-floor semi-street form

achieved a 71 percent load match, this rate increased to 93 percent for the semi-court on the same floor. . If no limit values were set for facades, these load match percentages would probably differ by 5-7, as in other design alternatives.

4.3.2 Density and load matching

Load matching values for all 3-storey alternatives are 100% and above, and those exceeding in the figure were also shown as 100%. As expected, the lowest load match percentages belong to the 9-storey design alternatives. While the percentage of load match varied between 43 and 59 in 9-storey alternatives, it was between 62 and 80 percent in 6-storey.

4.3.3 Orientation and load matching

The most significant difference was seen in different orientations of the semi-court form. The percentage of load match on 6 floors varied between 11-17; on 9 floors, it varied between 4-7. In other forms, the percentage of difference due to orientation was between 0-7.

4.4 How early decisions regarding the urban form at the block level affect the future residential buildings areas' UHI intensity?

The climate data used in the study are in epw format, and the climate data are available in the files hourly. 81 Normal epw files were compared to 81 modified epw files via Dragonfly to analyze urban heat island intensity differences. A comparison was made between the yearly average dry bulb temperature differences. The average temperature difference between the raw and modified epw data were approximately 1.05° C for İzmir and Konya, while 1.57° C for Van.

In the same climatic conditions, changes in UHI intensity were almost negligible (about 0.01 °C) due to built form, density, and orientation. In table 4.1, some of the cases' comparisons are shown as examples.

Table 4.1 Comparison of UHI intensity values of some cases

Built form – orientation Number of floors	Maximum Dry bulb temp. (°)	Minimum Dry bulb temp. (°)	Maximum Dry bulb temp. (°) with UHI	Minimum Dry bulb temp. (°) with UHI	Max. temp. diff. (°)	Average temp. diff. (°)
Izmir-Pavilion- 0°-3	40	-7	40	-5.5	14	1.04
Izmir-Pavilion- 0°-6	40	-7	40	-5.4	14.1	1.05
Izmir-Pavilion- 0°-9	40	-7	40	-5.4	14.1	1.05
Izmir-Pavilion- 22.5°-3	40	-7	40	-5.5	14	1.04
Izmir-Pavilion- 22.5°-6	40	-7	40	-5.4	14.1	1.05
Izmir-Pavilion- 22.5°-9	40	-7	40	-5.4	14.1	1.05
Izmir-Pavilion- 45°-3	40	-7	40	-5.5	14	1.04
Izmir-Pavilion- 45°-6	40	-7	40	-5.4	14.1	1.05
Izmir-Pavilion- 45°-9	40	-7	39.9	-5.4	14.1	1.05
Izmir-Semi-street-0°-9	40	-7	39.9	-5.4	14.1	1.05
Izmir-Semi-court-0°-9	40	-7	39.9	-5.4	14.1	1.06
Konya- Semi-court-0°-9	35	-14	34.3	-12.4	10.9	1.06
Konya- Semi-court-45°-9	35	-14	34.3	-12.4	10.9	1.06
Van- Semi-court-0°-9	31	-16.6	30.3	-14.1	10.6	1.57

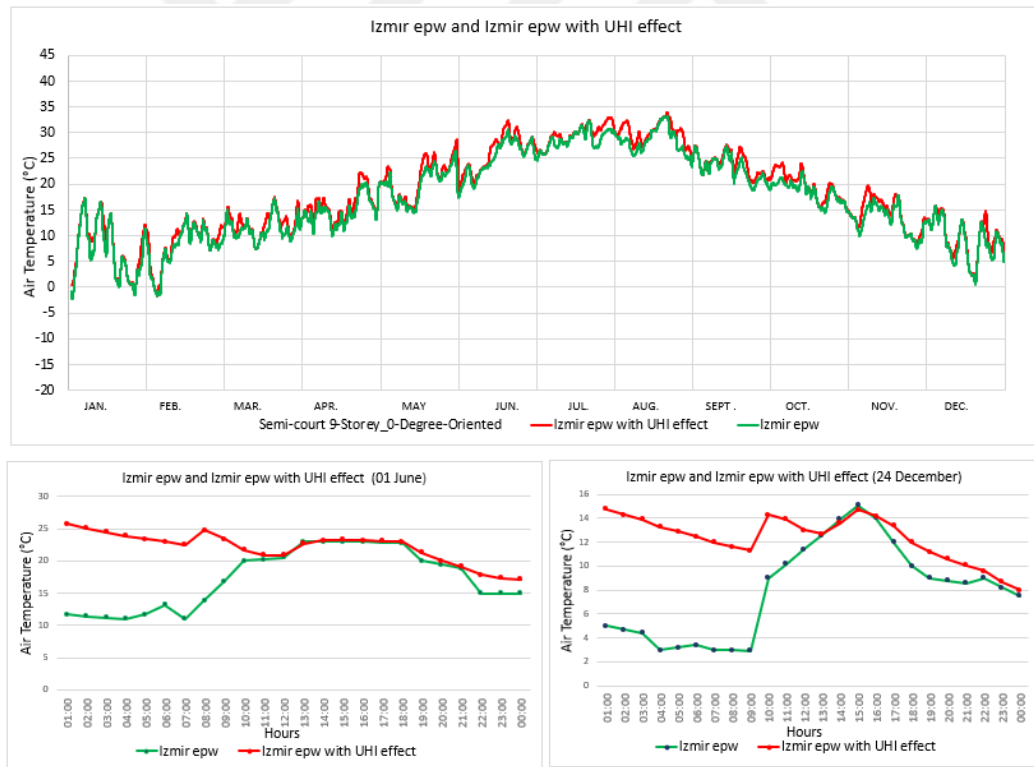
The reason why design decisions had an almost negligible effect on UHI intensity in this study can be explained as:

When it only be considered the effect of the built form on UHI intensity, the only variable parameter was the façade-to-side ratio (p.100), with the site coverages of all three forms equal. Minor differences might have been due to the difference in face-to-site ratios. Moreover, maybe it can be made the following inference: the façade-to-site ratio alone may not be an effective parameter on UHI.

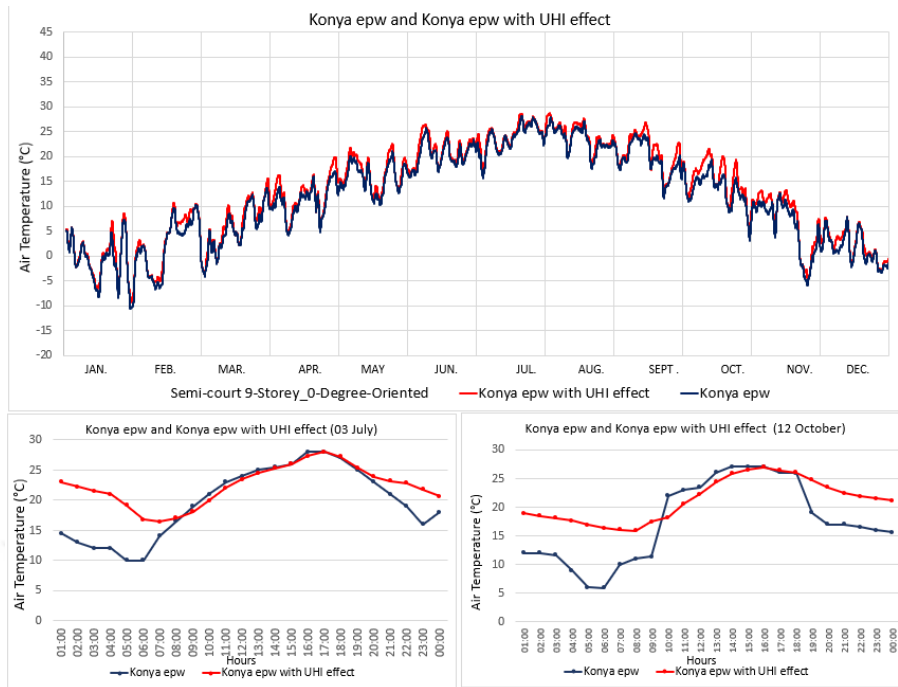
Considering only the effect of density on UHI intensity, footprint density ratios decreased as the height increased since the street widths were not constant. The effects of the increase in height and decrease in footprint density perhaps neutralized each other.

The reason that orientation did not affect UHI intensity can be explained by Dragonfly's calculation method. Dragonfly considers the canyon to be omnidirectional while calculating the average temperature change. Hence orientation was an ineffective parameter for this calculation.

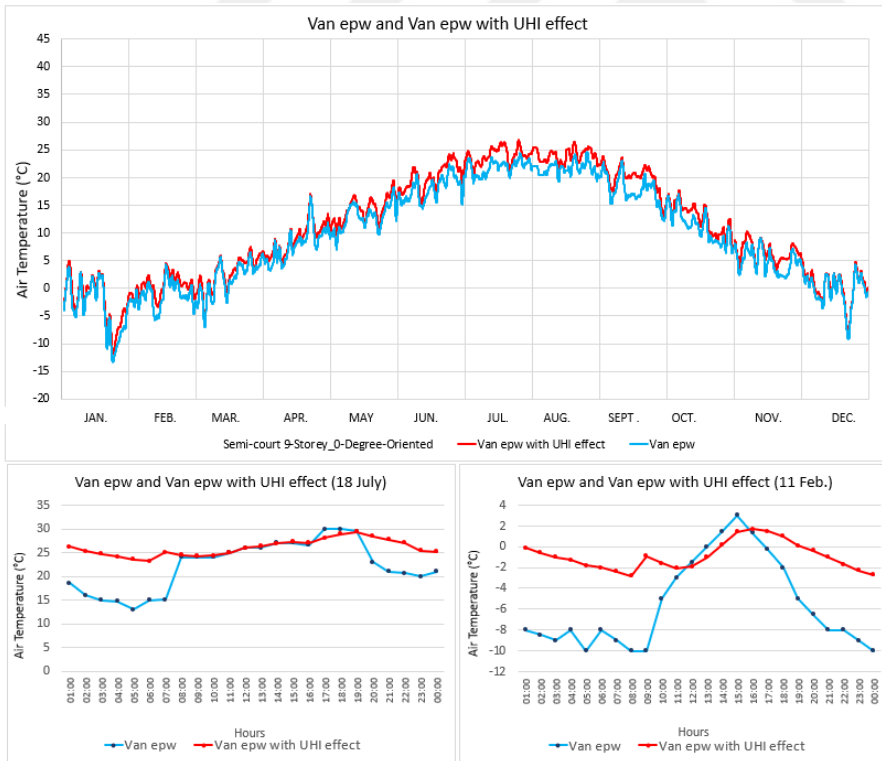
In figure 4.14, daily dry-bulb temperature values were compared with the modified values for the Semi-court, 0° oriented, 9-storey design alternative chosen as an example. As stated earlier, data in epw format is hourly. For this reason, daily temperatures were calculated with a 24 moving average. Moreover, hourly data were compared in more detail. For this, two days with the highest temperature differences were selected for all three cities. The maximum temperature difference for İzmir, Konya, and Van is 14.1, 10.9, and 10.6 °C, respectively.



(a) İzmir, Semi-court, 0° oriented, 9-storey



(b) Konya, Semi-court, 0° oriented, 9-storey



(c) Van, Semi-court, 0° oriented, 9-storey

Figure 4.14. Comparison of temperature data with and without UHI effect

4.5 How UHI affect the buildings' cooling and heating energy demand?

All the energy analysis results given so far in this chapter considered the UHI island effect. As mentioned earlier, simulations were run twice to understand how the UHI island effect affects energy needs. In this section, these results were compared with each other.

The figures below shows the buildings' annual total operational energy demands without the UHI effect (Figure 4.15) and with the UHI effect considered (Figure 4.16). Results showed that the energy demand demands were slightly higher when the UHI effect was not taken into account. While the difference in 3-storey design alternatives was around 0-1 %, this difference was around 3 % in 6 and 9-storey alternatives.

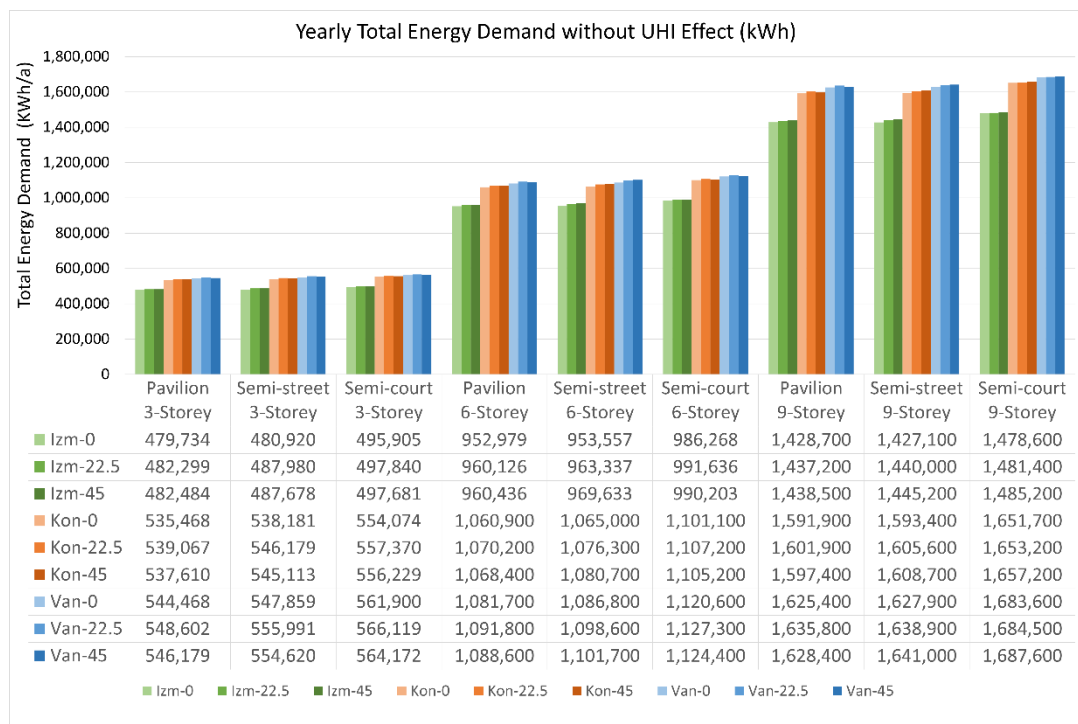


Figure 4.15. Annual total energy demand without UHI effect

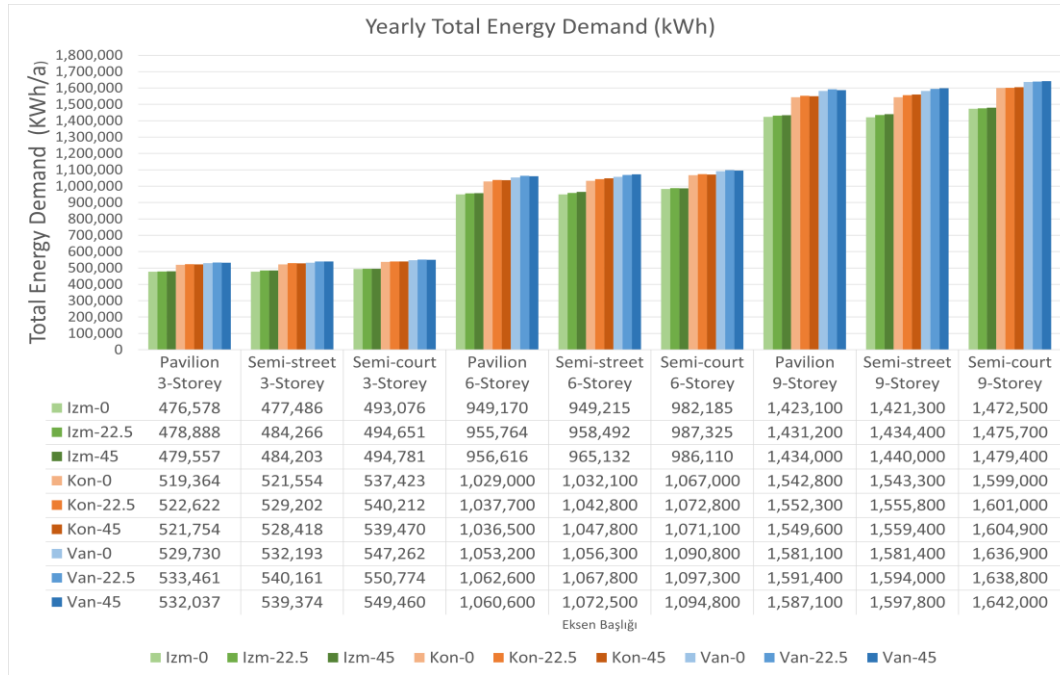


Figure 4.16. Annual total energy demand with UHI effect

However, total energy demand comparison may be superficial to assess the heat island effect. Because the heat island effect reduces the need for heating and increases the need for cooling, these two effects may neutralize each other.

Therefore heating and cooling EUI results also were compared separately. The figures on the following two pages show these EUI results.

When UHI was not considered, the results indicated that the annual heating EUI increased by 11-18 %, the annual cooling demand decreased by 19-58 %, compared to the situation in which it was considered.



Figure 4.17. Annual heating EUI with (bottom) and without the UHI effect (top)

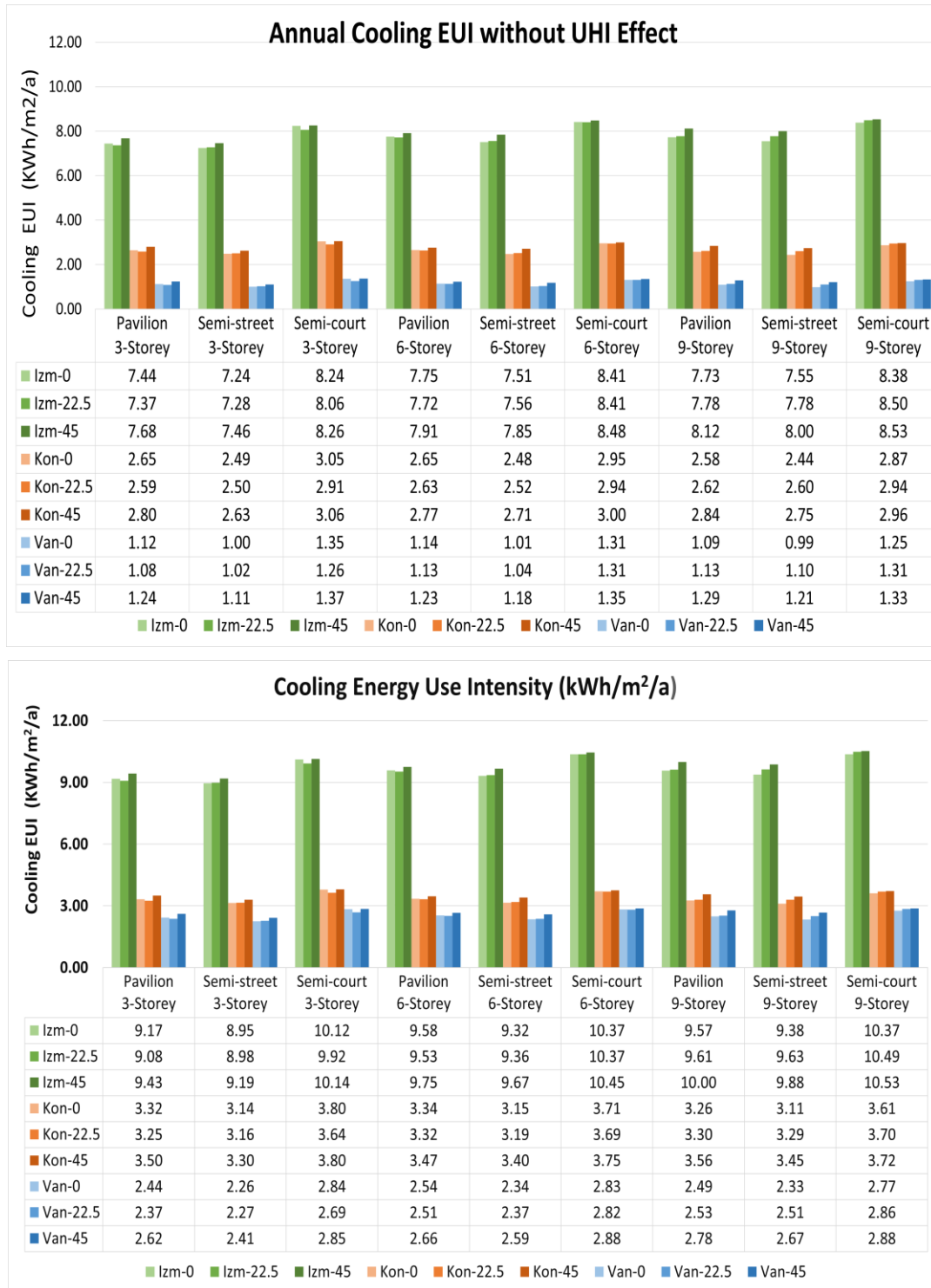


Figure 4.18. Annual cooling EUI with (bottom) and without the UHI effect (top)

In monthly comparisons, the effect of UHI on heating and cooling needs became more evident. To exemplify this situation, the changes in heating and cooling needs for the Semi-street, 0° oriented 9-storey design alternative were compared :

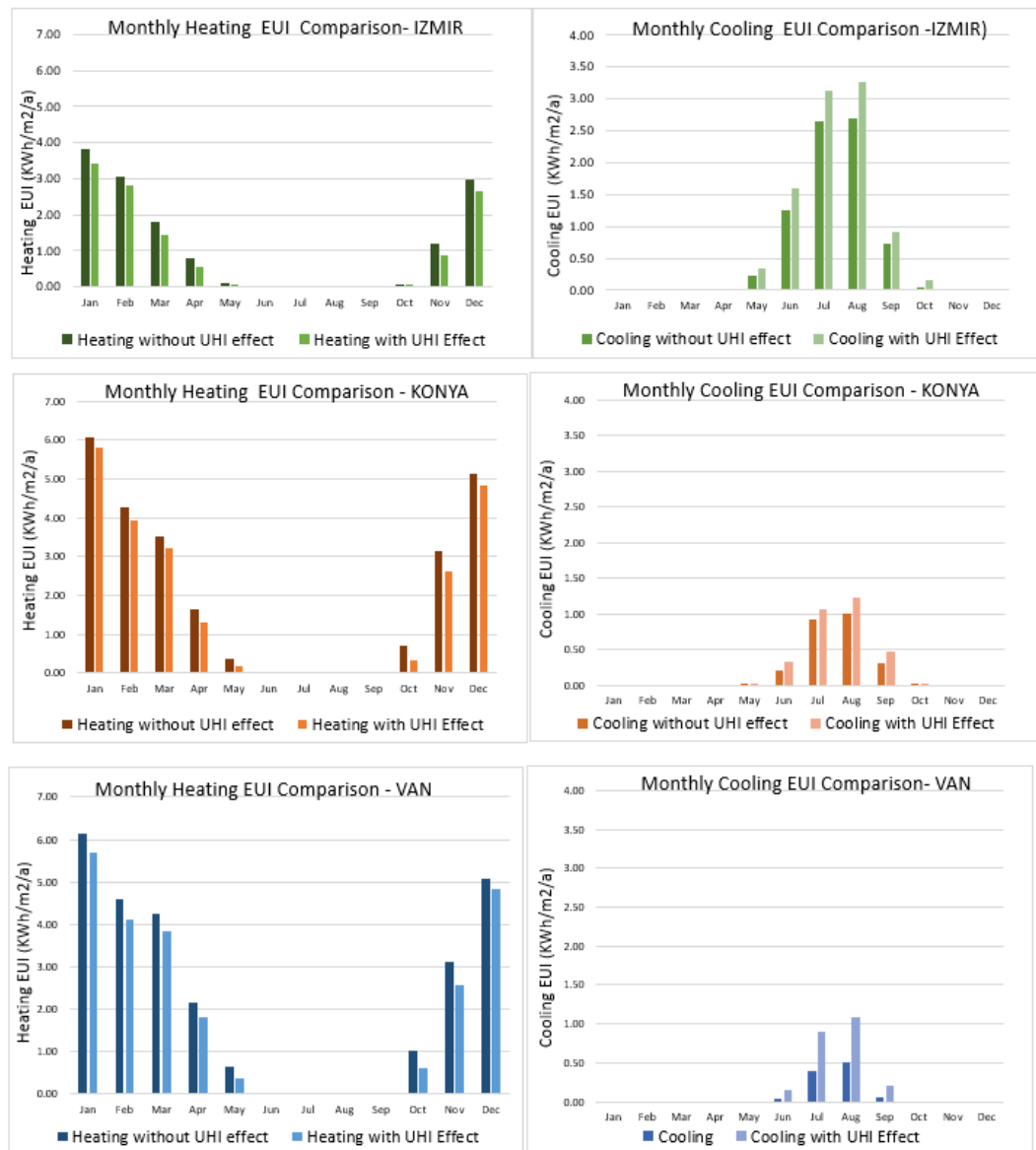


Figure 4.19. Comparison of monthly heating and cooling needs (kWh/m²/a) with and without UHI effect

In the case of the UHI effect was not considered, when the heating EUI values for İzmir (November- March) were compared, an increase of up to 35 percent; when the cooling values (June-September) were compared, a decrease of up to 22 percent was observed.

When the same comparisons were made for Konya and Van, an increase of up to 19 and 21 percent in heating EUI values; a decrease of 39 and 78 in cooling EUI values were observed, respectively.

4.6 How climate affect energy demand, solar energy potential, and UHI impacts’?

As mentioned in the methodology chapter, three locations belonging to different climate classes were selected at the same latitude to evaluate only the effect of the climate. Since these three cities are located at the same latitude, their solar power generation potentials were almost identical.

When the annual energy demands were compared, as expected, İzmir had the most advantages while Van had the highest energy demand. In the comparison made by keeping other parameters constant, the energy demands in Van were 11% higher than in İzmir. The difference between the energy demands of Van and Konya was 2% (see p.103, figure 4.2).

The annual heating, cooling and lighting EUI values were compared separately. When the annual heating EUI values are examined, the climate condition with the highest heating need was in Van; The average heating need per square meter was twice that of İzmir. The difference between Konya and Van was around 6-8 percent (see p. 104, figure 4.3).

As expected, the need for cooling was the highest in İzmir, approximately 2.5-3 times Van's. The lowest cooling need is in Van, and the cooling need in Konya is approximately thirty percent higher than that of Konya (see p.105, figure 4.4).

When the lighting needs were compared, İzmir was the most advantageous. Compared to İzmir, Konya and Van needed 6-7 and 13-14% more lighting, respectively (see p. 105, figure 4.4).

When the load matches were analyzed, all of them have already reached one hundred percent in the 3-storey alternatives. In other alternatives, since the energy production potentials were almost equal, the determining factor had naturally been the energy demands. Exceptions resulted from the limit values set for PV analysis, as stated earlier. Load matching varied between 43 and 80 % in design alternatives other than 3-floors in Van, 44-83% in Konya, and 48-93 % in İzmir (see p. 110, figure 4.9).

However, a point should not be overlooked here: u-values were taken as the limit values specified in the standard while creating the simulation input parameters, and these values were different for all three climates (p. 95). If all simulations were run only for the u-values of İzmir or only Van, the total energy difference would probably be higher.

The normal and modified epw data average temperature difference was approximately 1.05° C for İzmir and Konya, while 1.57° C for Van. The maximum difference in comparing the total operational energy demand with and without the UHI effect is 0-1 percent for 3-storey alternatives; For floors 6 and 9, it was around 3 percent. These values were the same in all climates (see p.119-120 Figures 4.15 & 4.16).

When UHI was not considered, the results indicated that the annual heating EUI increased by 16-18 % for İzmir; 11-12% for Konya; % 12-13 for Van, compared to the situation in which it was considered (see p. 121 figure 4.17). The annual cooling demand decreased by 19-20 % for İzmir; 20-22% for Konya; % 52-58 for Van (see p. 122 figure 4.18)



CHAPTER 5

CONCLUSION

This section aims to highlight the study's findings, explain the study's limitations, and make recommendations for future studies.

As mentioned in the introduction chapter, urban areas have become the nodal points of the energy problem. Transforming these nodal points into solution points is of great importance for the realization of energy transition. The study's starting point is the idea of using urban design as a strategic tool that contributes to energy transition. In order to achieve this, first of all, starting from the fact that the effects of design decisions should be well understood; the study focused on understanding the effects of decisions taken at the early design stage on the energy performance of buildings.

The study was carried out through simulations in the Grasshopper environment, and the results were examined in detail in the previous chapter. A summary of the findings is presented in the section below.

5.1 What were the main study findings?

Q1: How early decisions regarding the urban form at the block level affect the future residential buildings' operational (cooling, heating, lighting) energy demand?

- In terms of annual total energy demand (kWh), Pavilion (the most compact form among the identified forms) performed the best while Semi-court (the least compact form) was the worst.
- When the annual total EUI values (annual total energy demand per m²) were compared, Pavilion and Semi- Street had almost the same EUI, while semi-court had slightly higher EUI values.

- Pavilion and Semi-street values were close in heating & cooling EUIs, as in total annual EUI. The Pavilion performed best when heating EUI values were considered, while semi-street was the best when cooling EUI values were considered.
- The differences between building forms' heating EUI values ranged between 7-11%; cooling EUI values ranged between 7-26 %. The lighting EUI values were close to each other; the percentage of change between values was around 4 at most.
- Annual energy demand increased with the density. On the other hand, annual EUI values were almost the same in different densities. The maximum difference between EUI values was found as 2%.
- A clear link between orientation and energy demand could not be found. None of the regression analyzes yielded significant results.

Q2: How early decisions regarding the urban form at the block level affect the future residential buildings' active (PV Systems) solar energy potential?

- In terms of solar energy potential, Semi-court had the potential to produce 3% to 33% more energy than Pavilion and Semi-street.
- As the density increased, the energy production potential per square meter decreased. The energy production potential per square meter between 3 floors and 9 floors decreases by 60-65 percent.
- The relationship between orientation and solar energy potential was more evident in 6 and 9-layer design alternatives. Depending on the orientation, the highest rate of change in solar energy potential was 23 percent.

Q3: How early decisions regarding the urban form at the block level affect the trade-offs between the buildings' energy demand and solar energy potential?

- Considering the load matching results, semi-court performed the best among these three forms. The difference was most evident in the 6-storey design alternatives.
- The lowest load match percentages belong to the 9-storey design alternatives.
- The most significant load matching percentages' difference was observed in different orientations of the semi-court form; it varied between 4-17.

Q4: How early decisions regarding the urban form at the block level affect the future residential buildings areas' UHI intensity?

- In the same climatic conditions, changes in UHI intensity were almost negligible (about 0.01 °C) due to built form, density, and orientation.
- The raw and modified epw data's average temperature difference was approximately 1.05° C for İzmir and Konya, while 1.57° C for Van.

Q5: How UHI affect the buildings' cooling and heating energy demand?

- When UHI was not considered, the results indicated that the annual heating EUI increased by 11-18 %, compared to the situation in which it was considered. The annual cooling demand decreased by 19-58 %.

Q6: How climate affect energy demand, solar energy potential, and UHI intensity?

- Van, which is in the D climate class according to the Köppen-Geiger classification system, had the highest annual total energy demand. The average heating need per square meter was twice that of İzmir, which is in the C climate class.
- The need for cooling was the highest in İzmir (Csa), approximately 2.5-3 times Van's (Dsb).

- İzmir (Csa) was the most advantageous in terms of lighting energy demand, while Van (Dsb) was the least.
- Van was the most disadvantaged city in load matching.
- While UHI affected İzmir (Csa) the most in terms of heating needs, it affected Van (Dsb) the most in terms of cooling needs (When UHI was not considered, the annual heating EUI increased by 16-18 % for İzmir and the annual cooling demand decreased by % 52-58 for Van).

5.2 What inferences can be made for Urban Design?

Based on the study's findings, the following inferences can be made:

- The more compact forms are more advantageous when compared to the annual total energy requirement.

However, this situation is reversed when solar energy potentials are analyzed.

This time, forms with low compactness ratios are more advantageous.

Looking at the trade-off between energy demand and supply, the form with a lower compactness ratio performed best. Based on this study alone, it cannot be concluded that forms with less compactness are more advantageous for load matching. Thus, the following conclusion can be drawn. Instead of assessing only energy demand or only energy production potential, it may be more meaningful to evaluate by looking at the interactions between energy demand and energy production potential.

- In the study, the density was controlled by the floor height. Although the energy requirement increased as the density increased, the energy requirement per m² remained almost constant. In other words, the amount reflected on the energy consumption bills of the people living in a 9-storey building is the same as the people living in a 3-storey building.

In terms of solar energy potential, the situation is the opposite. Although the total energy produced increased due to the increase in the facade surfaces as the density increased, the production potential per square meter decreased.

Similarly, the density increase was a disadvantage when examining the load matching. While all 3-storey buildings could meet all the energy they need from solar energy, this has not been possible in 9-storey design alternatives. The same conclusion can be drawn from here: it may be more appropriate to consider trade-offs when making evaluations.

- Although orientation has an impact on energy supply-demand and trade-offs, this effect is not linear. Therefore, it would not be healthy to generalize; it should be considered separately for each case.
- UHI has significant effects on the heating and cooling needs of buildings. Neglecting the UHI effect while performing energy performance analysis may lead to misleading results.

The effects of the parameters determined in the study on UHI intensity were negligible, with a maximum difference of 0.01 degrees. On the other hand, the annual average temperature difference between the standard and modified climate data by considering the UHI effect varied from location to location. So, it can be concluded that UHI intensity may differ in different climatic conditions.

Similarly, the UHI effect on the heating and cooling needs of the buildings varies according to climatic conditions. For example, while it is most effective on the heating need in İzmir, which belongs to the C climate class, it has the most impact on the cooling need in Van, which belongs to the D climate class.

- Climate has been a decisive factor in trade-off between energy consumption and production. Significant differences were found between the load matching results of similarly designed areas in different climates.

5.3 What were the main limitations of the study?

- *Model Verification* While hypothetical models allow for simpler and more controlled energy performance analysis by minimizing the complexity of the city form, deviations may occur in the results because they cannot fully describe the "real" urban forms (Oh & Kim, 2019). Therefore, in energy performance analysis, the relationship between simplifying and accuracy needs to be examined more. Although hypothetical models were used in the study based on previous research, the fact that the verifications of the models were not made in the study was a limitation.
- *Simulation Validation* The study was carried out with a physics-based modeling approach, so all the disadvantages of this approach also apply to this study (p. 71). The results obtained from this study have not been compared and checked against historical data or actually measured data. Although this will not pose a problem for studies based on the comparison of various form parameters (Natanian, 2020) , it was still one of the limitations of this study.
- *Simulation Times/Iterations*, Completing the simulations of each design alternative took approximately 3-20 minutes. Although the simulation times were not long, it took more time than expected to obtain all the results. In fact, all simulations were tuned to switch to the next simulation via Colibri automatically. However, the study could not be carried out iteratively due to the insufficient technical equipment of the computer used. Therefore, almost every simulation was run individually.

5.4 Recommendations for further research

The work is far from complete as it stands. In future studies, it may become more comprehensive by including the following considerations:

- *Future climate data:* Considering that a building's lifetime is 50 years or more, how climate change will affect the energy demand of buildings is an important question that needs to be analyzed (Berger et al., 2014; Camilleri et al., 2001; Hosseini et al., 2018; Kalvelage et al., 2014; Mangan & Koçlar Oral, 2020; Wan et al., 2011; H. Wang & Chen, 2014; Zhou et al., 2013). Therefore, it may be meaningful to include future data in the research framework. Due to insufficient data, it could not be included in the scope of this study.
- *Daylight availability:* Trade-offs between energy demand and supply is one of the critical reference points to be considered in the urban design process (Kanters & Wall, 2014; Naboni et al., 2019; Natanian, Aleksandrowicz, et al., 2019a; Wall et al., 2017). The relationship between active and passive energy is as essential as the trade-offs between the energy demand and supply. The relationship between daylight and PV systems should be investigated more extensively.
- *Mixed-use(diversity) and Green areas:* Mixed-use (p. 45) and green areas (p. 47) also are urban form characters directly related to energy performance analysis. Although their importance was mentioned in the literature review, these two characters have not been included in the scope of the study; it will be meaningful to examine them in more detail in future studies.
- *Climate adaptation measures:* In this study, climate change mitigation measures were emphasized through energy performance analysis. As mentioned in the literature review, it is important to consider mitigation measures and adaptation measures together. In future studies, it may be useful to examine how the urban form characters examined in this study relate to adaptation measures and to see possible contradictions and trade-offs.



REFERENCES

- Abbasabadi, N., & Mehdi Ashayeri, J. K. (2019). Urban energy use modeling methods and tools: A review and an outlook. *Building and Environment*, 161(May), 106270. <https://doi.org/10.1016/j.buildenv.2019.106270>
- Aghamolaei, R., Shamsi, M. H., Tahsildoost, M., & O'Donnell, J. (2018). Review of district-scale energy performance analysis: Outlooks towards holistic urban frameworks. *Sustainable Cities and Society*, 41(March), 252–264. <https://doi.org/10.1016/j.scs.2018.05.048>
- Aiko, N., Bruno, B., Norford, L., & Christoph F, R. (2015). *Urban Heat Island Effect within Urban Design Process*.
- Akbari, H., Kim, D. M., Bretz, S. E., & Hanford, J. W. (1997). *Peak power and cooling energy savings of shade trees*. 25, 139–148.
- Aksoy, U. T., & Inalli, M. (2006). *Impacts of some building passive design parameters on heating demand for a cold region*. 41, 1742–1754. <https://doi.org/10.1016/j.buildenv.2005.07.011>
- Aleksandrowicz, O., Vuckovic, M., Kiesel, K., & Mahdavi, A. (2017). Current trends in urban heat island mitigation research: Observations based on a comprehensive research repository. *Urban Climate*, 21(April), 1–26. <https://doi.org/10.1016/j.uclim.2017.04.002>
- Ali-toudert, F. (2009). Energy Efficiency of Urban Buildings: Significance of Urban Geometry, Building Construction and Climate Conditions. *The Seventh International Conference on Urban Climate, Yokohama, Japan, July*, 29–32.
- Ali, U., Shamsi, M. H., Hoare, C., Mangina, E., & O'Donnell, J. (2021). Review of urban building energy modeling (UBEM) approaches, methods and tools using qualitative and quantitative analysis. *Energy and Buildings*, 246, 111073. <https://doi.org/10.1016/j.enbuild.2021.111073>

- Allegrini, J., Dorer, V., & Carmeliet, J. (2012). Influence of the urban microclimate in street canyons on the energy demand for space cooling and heating of buildings. *Energy and Buildings*, 55, 823–832. <https://doi.org/10.1016/j.enbuild.2012.10.013>
- Allegrini, J., Orehounig, K., Mavromatidis, G., Ruesch, F., Dorer, V., & Evins, R. (2015). A review of modelling approaches and tools for the simulation of district-scale energy systems. *Renewable and Sustainable Energy Reviews*, 52, 1391–1404. <https://doi.org/10.1016/j.rser.2015.07.123>
- Allen, S. (1999). *Points + lines: Diagrams and projects for the city*. New York: Princeton Architectural Press.
- Amaral, A. R., Rodrigues, E., Rodrigues Gaspar, A., & Gomes, Á. (2018). Review on performance aspects of nearly zero-energy districts. *Sustainable Cities and Society*, 43(June), 406–420. <https://doi.org/10.1016/j.scs.2018.08.039>
- Ashrafian, T. (2016). A New Approach to Define Economically Applicable Energy Efficient Retrofit Solutions for Residential Buildings in Turkey. In *Istanbul Technical University* (Vol. 66, Issue July).
- Baetens, R., Coninck, R. De, Jorissen, F., & Picard, D. (2015). *OpenIDEAS - An Open Framework for Integrated District Energy Simulations OPENIDEAS – AN OPEN FRAMEWORK FOR INTEGRATED DISTRICT ENERGY. September.*
- Bay, J. H. p., & Lehmann, S. (2017). *Growing Compact: Urban Form, Density and Sustainability.*
- Bednar, Thomas & Haufe, Nadine & Bothe, Dominik & Forster, Julia & Fritz, Sara & Kaufmann, Thomas & Eder-Neuhauser, Peter & Pfaffenbichler, Paul & Rab, Nikolaus & Schleicher, Johannes & Weinwurm, Gudrun & Winkler, Christina & Ziegler, Manuel. (2016). Urbanes Energie- und Mobilitätssystem Doktoratskolleg (URBEM-DK) Ergebnisbericht.

- Berghauser Pont, M. Y., & Haupt, P. A. (2007). The relation between urban form and density. *Urban Morphology*, 11(1), 62–65.
- Bertaud, A. (2001). Metropolis : A Measure of the Spatial Organization of 7 Large Cities. *Http://Alainbertaud.Com/*, 1–22.
- Borlin, G., Pinheiro, M. D., Beatriz, M., & Condessa, M. (2013). *Nearly Zero Energy applied to urban zones – Main challenges and perspectives*. 727–734.
- Bourdic, L., Salat, S., Nowacki, C., Bourdic, L., Salat, S., & Nowacki, C. (2012). *Assessing cities : a new system of cross-scale spatial indicators* *Assessing cities : a new system of cross-scale spatial indicators*. 3218. <https://doi.org/10.1080/09613218.2012.703488>
- Bouyer, J., Musy, M., Huang, Y., & Athamena, K. (2017). *Effect by Urban Design* : 164–181.
- Bruse, M., & Fleer, H. (1998). Simulating surface-plant-air interactions inside urban environments with a three dimensional numerical model. *Environmental Modelling and Software*, 13(3–4), 373–384. [https://doi.org/10.1016/S1364-8152\(98\)00042-5](https://doi.org/10.1016/S1364-8152(98)00042-5)
- Bueno, B., Norford, L., Hidalgo, J., & Pigeon, G. (2013). *The urban weather generator*. 1493. <https://doi.org/10.1080/19401493.2012.718797>
- Calthorpe Analytics. (2017). *The Ultimate Technical Guide to UrbanFootprint*.
- Cervero, R., & Kockelman, K. (1997). *TRAVEL DEMAND AND THE 3Ds : DENSITY , DESIGN DIVERSITY , AND*. 2(3), 199–219.
- Cheng, V., Steemers, K., Montavon, M., & Compagnon, R. (2006). Urban form, density and solar potential. *PLEA 2006 - 23rd International Conference on Passive and Low Energy Architecture, Conference Proceedings, September*, 6–8.
- Cheung, H. K. W., Coles, D., & Levermore, G. J. (2016). *Urban heat island analysis*

- of Greater Manchester , UK using sky view factor analysis.
<https://doi.org/10.1177/0143624415588890>
- Chokhachian, A., Perini, K., Giulini, S., & Auer, T. (2017). Mathematical Generative Approach on Performance Based Urban Form Design. *International Conference on Urban Comfort and Environmental Quality.*, September, 1–5.
- Compagnon, R. (2004). Solar and daylight availability in the urban fabric. *Energy and Buildings*, 36(4), 321–328. <https://doi.org/10.1016/j.enbuild.2004.01.009>
- Cowan, R. (2005) *The Dictionary of Urbanism*. Tisbury: Streetwise Press
- Creutzig, F., Fernandez, B., Haberl, H., Khosla, R., Mulugetta, Y., & Seto, K. C. (2016). Beyond Technology: Demand-Side Solutions for Climate Change Mitigation. *Annual Review of Environment and Resources*, 41, 173–198. <https://doi.org/10.1146/annurev-environ-110615-085428>
- Çalışkan, O. (2004). *Urban Compactness : A Study of Ankara Urban Form* (Issue July).
- de Coninck, H., A. Revi, M. Babiker, P. Bertoldi, M. Buckeridge, A. Cartwright, W. Dong, J. Ford, S. Fuss, J.-C. Hourcade, D. Ley, R. Mechler, P. Newman, A. Revokatova, S. Schultz, L. Steg, and T. Sugiyama, 2018: Strengthening and Implementing the Global Response. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [MassonDelmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.
- De Pascali, P., & Bagaini, A. (2019). Energy transition and urban planning for local development. A critical review of the evolution of integrated spatial and energy planning. *Energies*, 12(1), 1–21. <https://doi.org/10.3390/en12010035>

- DeKAY, M., & Brown, G. . (2014). *Mark DeKay, G. Z. Brown-Sun, Wind, and Light_Architectural Design Strategies-Wiley (2014).*
- Depecker, P., Menezo, C., Virgone, J., & Lepers, S. (2001). *Design of buildings shape and energetic consumption.* 36, 627–635.
- Dhar, T. K., & Khirfan, L. (2017). Climate change adaptation in the urban planning and design research: missing links and research agenda. *Journal of Environmental Planning and Management*, 60(4), 602–627. <https://doi.org/10.1080/09640568.2016.1178107>
- Dirksen, M., Ronda, R. J., Theeuwes, N. E., & Pagani, G. A. (2019). Sky view factor calculations and its application in urban heat island studies. *Urban Climate*, 30(May), 100498. <https://doi.org/10.1016/j.uclim.2019.100498>
- Donovan, G. H., & Butry, D. T. (2009). *The value of shade : Estimating the effect of urban trees on summertime electricity use.* 41, 662–668. <https://doi.org/10.1016/j.enbuild.2009.01.002>
- Dorer, V., Allegrini, J., Orehounig, K., Moonen, P., Upadhyay, G., Kämpf, J., & Carmeliet, J. (2013). MODELLING THE URBAN MICROCLIMATE AND ITS IMPACT ON THE ENERGY DEMAND OF BUILDINGS AND BUILDING CLUSTERS Empa , Laboratory for Building Science and Technology , Duebendorf , Switzerland ETHZ , Chair of Building Physics , Z{ü}rich , Switzerland EPFL , Solar. *13th Conference of International Building Performance Simulation Association, Chamb{é}ry, France, August 26-28*, 3483–3489.
- Eltaweel, A., & SU, Y. (2017). Parametric design and daylighting: A literature review. *Renewable and Sustainable Energy Reviews*, 73(February), 1086–1103. <https://doi.org/10.1016/j.rser.2017.02.011>
- EPBD-recast. (2010). Contribution à l'exploration radiologique des vertèbres lombaires agrandies et des quatre derniers interlignes vertébraux sur un seul film. In *La Presse médicale* (Vol. 63, Issue 30).

- Erell, E., & Williamson, T. (2006). *SIMULATING AIR TEMPERATURE IN AN URBAN STREET CANYON IN ALL WEATHER CONDITIONS USING MEASURED DATA AT A REFERENCE METEOROLOGICAL STATION*. 1694(April), 1671–1694. <https://doi.org/10.1002/joc>
- Esiyok, U. (2006). Energy Consumption and Thermal Performance of Typical Residential Buildings in Turkey. *University of Dortmund*.
- European Commission. (2020). *2020 climate & energy package*.
- Evans, S., Liddiard, R., & Steadman, P. (2017). 3DStock: A new kind of three-dimensional model of the building stock of England and Wales, for use in energy analysis. *Environment and Planning B: Urban Analytics and City Science*, 44(2), 227–255. <https://doi.org/10.1177/0265813516652898>
- Fahmy, M., & Sharples, S. (2009). On the development of an urban passive thermal comfort system in Cairo , Egypt. *Building and Environment*, 44(9), 1907–1916. <https://doi.org/10.1016/j.buildenv.2009.01.010>
- Fang, Y. (2017). Optimization of Daylighting and Energy Performance Using Parametric Design, Simulation Modeling, and Genetic Algorithms. In *North Carolina State University*.
- Ferrando, M., Causone, F., Hong, T., & Chen, Y. (2020). Urban building energy modeling (UBEM) tools: A state-of-the-art review of bottom-up physics-based approaches. *Sustainable Cities and Society*, 62(June), 102408. <https://doi.org/10.1016/j.scs.2020.102408>
- Fleischmann, M., Romice, O., & Porta, S. (2020). *Measuring urban form : Overcoming terminological inconsistencies for a quantitative and comprehensive morphologic analysis of cities*. 0(0), 1–18. <https://doi.org/10.1177/2399808320910444>
- Fonseca, J. A., Nguyen, T., Schlueter, A., & Marechal, F. (2016). City Energy Analyst (CEA): Integrated framework for analysis and optimization of

- building energy systems in neighborhoods and city districts. *Energy & Buildings*, 113, 202–226. <https://doi.org/10.1016/j.enbuild.2015.11.055>
- Frank, L. D., & Pivo, G. (1991). *Impacts of Mixed Use and Density on Utilization of Three Modes of Travel : Single-Occupant Vehicle , Transit , and Walking*.
- Frayssinet, L., Merlier, L., Kuznik, F., Hubert, J. L., Milliez, M., & Roux, J. J. (2018). Modeling the heating and cooling energy demand of urban buildings at city scale. *Renewable and Sustainable Energy Reviews*, 81(March 2017), 2318–2327. <https://doi.org/10.1016/j.rser.2017.06.040>
- Gago, E. J., Roldan, J., Pacheco-Torres, R., & Ordóñez, J. (2013). The city and urban heat islands: A review of strategies to mitigate adverse effects. *Renewable and Sustainable Energy Reviews*, 25, 749–758. <https://doi.org/10.1016/j.rser.2013.05.057>
- Global Alliance for Buildings and Construction, International Energy Agency and the United Nations Environment Programme (2019): 2019 global status report for buildings and construction: Towards a zero-emission, efficient and resilient buildings and construction sector
- GlobalABC/IEA/UNEP (Global Alliance for Buildings and Construction, International Energy Agency, and the United Nations Environment Programme) (2020): GlobalABC Roadmap for Buildings and Construction: Towards a zero-emission, efficient and resilient buildings and construction sector, IEA, Paris.
- Godoy-shimizu, D., Steadman, P., Evans, S., & Densification, U. (2021). *Density and morphology : from the building scale to the city scale*. <https://doi.org/10.5334/bc.83>
- Gorsevski, V., Taha, H., Quattrochi, D., & Luvall, J. (1998). Air Pollution Prevention Through Urban Heat Island Mitigation: An Update on the Urban Heat Island Pilot Project. *Proceedings of the ACEEE Summer Study*, x, 23–32. <https://doi.org/10.1017/S0963926807004373>

- Gratia, E. (2003). *Design of low energy office buildings*. 35.
- Grubler, Arnulf & Bai, Xuemei & Buettner, T. & Dhakal, Shobhakar & Fisk, David & Ichinose, Toshiaki & Keirstead, J.E. & Sammer, G. & Satterthwaite, David & Schulz, Niels & Shah, Neelkumar & Steinberger, Julia & Weisz, Helga. (2012). *Urban energy systems. Global Energy Assessment-Toward a Sustainable Future*. 1307-1400. 10.1017/CBO9780511793677.024.
- Hachem, C., Fazio, P., & Athienitis, A. (2013). Solar optimized residential neighborhoods: Evaluation and design methodology. *Solar Energy*, 95, 42–64. <https://doi.org/10.1016/j.solener.2013.06.002>
- Han, Y., Taylor, J. E., & Laura, A. (2017). Exploring mutual shading and mutual reflection inter-building effects on building energy performance q. *Applied Energy*, 185, 1556–1564. <https://doi.org/10.1016/j.apenergy.2015.10.170>
- Hernandez, C. R. B. (2006). Thinking parametric design: Introducing parametric Gaudi. *Design Studies*, 27(3), 309–324. <https://doi.org/10.1016/j.destud.2005.11.006>
- Hess, P. (2021). *Encyclopedia of Quality of Life and Well-Being Research*. 1–6.
- Hoffmann, P., Krueger, O., & Schlünzen, K. H. (2012). A statistical model for the urban heat island and its application to a climate change scenario. *International Journal of Climatology*, 32(8), 1238–1248. <https://doi.org/10.1002/joc.2348>
- Hong, T., Chen, Y., Lee, S. H., & Piette, M. A. (2016). *CityBES: A Web-based Platform to Support City-Scale Building Energy CityBES: A Web-based Platform to Support City-Scale Building Energy Efficiency*. July.
- Hong, T., Chen, Y., Luo, X., Luo, N., & Lee, S. H. (2020). Ten questions on urban building energy modeling. *Building and Environment*, 168(October 2019), 106508. <https://doi.org/10.1016/j.buildenv.2019.106508>
- Ibrahim, Y., Kershaw, T., Shepherd, P., & Coley, D. (2021). On the optimisation of urban form design, energy consumption and outdoor thermal comfort using a

parametric workflow in a hot arid zone. *Energies*, 14(13).
<https://doi.org/10.3390/en14134026>

ICLEI – Local Governments for Sustainability, UNEP, and UN-Habitat (2009). Sustainable Urban Energy Planning, <https://mirror.unhabitat.org/pmss/listItemDetails.aspx?publicationID=2839>

IEA (2019), *The Critical Role of Buildings*, IEA, Paris
<https://www.iea.org/reports/the-critical-role-of-buildings>

Ionescu, C., Baracu, T., Vlad, G. E., Necula, H., & Badea, A. (2015). The historical evolution of the energy efficient buildings. *Renewable and Sustainable Energy Reviews*, 49, 243–253. <https://doi.org/10.1016/j.rser.2015.04.062>

IRENA (2016), *Renewable Energy in Cities*, International Renewable Energy Agency (IRENA), Abu Dhabi, www.irena.org.

IRENA. (2016). The Power to Change: Solar and Wind Cost Reduction Potential to 2025. In *International Renewable Energy Agency* (Issue June).

IRENA (2018), *Global Energy Transformation: A roadmap to 2050*, International Renewable Energy Agency, Abu Dhabi.

IRENA. (2020). Renewable Power Generation Costs in 2020. In *International Renewable Energy Agency*. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf

IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC, 2018: Annex I: Glossary [Matthews, J.B.R. (ed.)]. In: *Global Warming of*

1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press

Jabareen, Y. R. (2006). *Sustainable Urban Forms*. 3, 38–52.
<https://doi.org/10.1177/0739456X05285119>

Jaganmohan, M., Knapp, S., Buchmann, C. M., & Schwarz, N. (2016). The Bigger, the Better? The Influence of Urban Green Space Design on Cooling Effects for Residential Areas. *Journal of Environmental Quality*, 45(1), 134–145.
<https://doi.org/10.2134/jeq2015.01.0062>

Jenks, M., & Burgess, R. (2004). *Compact Cities Sustainable Urban Forms for Developing Countries*.

Jenks, M., Burton, E., & Williams, K. (2005). *The Compact City a Sustainable Urban Form*.

Jiang, Y., Hou, L., Shi, T., & Gui, Q. (2017). A review of urban planning research for climate change. *Sustainability (Switzerland)*, 9(12).
<https://doi.org/10.3390/su9122224>

Johari, F., Peronato, G., Sadeghian, P., Zhao, X., & Widén, J. (2020). Urban building energy modeling: State of the art and future prospects. *Renewable and Sustainable Energy Reviews*, 128(May).
<https://doi.org/10.1016/j.rser.2020.109902>

Jon Van Til (1979) Spatial Form and Structure in a Possible Future: Some Implications of Energy Shortfall for Urban Planning, *Journal of the American Planning Association*, 45:3, 318-329, DOI: 10.1080/01944367908976970

- Juwet, G., & Ryckewaert, M. (2018). Energy transition in the nebular city: Connecting transition thinking, metabolism studies, and urban design. *Sustainability (Switzerland)*, 10(4). <https://doi.org/10.3390/su10040955>
- Kang, J. N., Wei, Y. M., Liu, L. C., Han, R., Yu, B. Y., & Wang, J. W. (2020). Energy systems for climate change mitigation: A systematic review. *Applied Energy*, 263(November 2019), 114602. <https://doi.org/10.1016/j.apenergy.2020.114602>
- Kanters, J., & Horvat, M. (2012a). Solar energy as a design parameter in urban planning. *Energy Procedia*, 30, 1143–1152. <https://doi.org/10.1016/j.egypro.2012.11.127>
- Kanters, J., & Horvat, M. (2012b). *Solar energy as a design parameter in urban planning*. 30, 1143–1152. <https://doi.org/10.1016/j.egypro.2012.11.127>
- Kanters, J., & Wall, M. (2014). The impact of urban design decisions on net zero energy solar buildings in Sweden. *Urban, Planning and Transport Research*, 2(1), 312–332. <https://doi.org/10.1080/21650020.2014.939297>
- Kanters, J., (2015). Planning for solar buildings in urban environments. An analysis of the design process, methods and tools. PhD thesis. Report EBD-T--15/19, Div. of Energy and Building Design, Lund University.
- Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z., & Djurovic-Petrovic, M. (2010). A review of bottom-up building stock models for energy consumption in the residential sector. *Building and Environment*, 45(7), 1683–1697. <https://doi.org/10.1016/j.buildenv.2010.01.021>
- Kenworthy, J. R., Laube, F. B., & Newman, P., Dr. (1999). *An international sourcebook of automobile dependence in cities, 1960-1990*. University Press of Colorado.
- Knowles, R. L. (1974). *Energy and form; an ecological approach to urban growth*. MIT Press.

- Knowles, R. L. (2003). The solar envelope: Its meaning for energy and buildings. *Energy and Buildings*, 35(1), 15–25. [https://doi.org/10.1016/S0378-7788\(02\)00076-2](https://doi.org/10.1016/S0378-7788(02)00076-2)
- Ko, Y., & Radke, J. D. (2014). The effect of urban form and residential cooling energy use in Sacramento, California. *Environ. Plann. B Plann. Des.*, 41(4), 573–593. <https://doi.org/10.1068/b12038p>
- Kolokotroni, M., Giannitsaris, I., & Watkins, R. (2006). The effect of the London urban heat island on building summer cooling demand and night ventilation strategies. *Solar Energy*, 80(4), 383–392. <https://doi.org/10.1016/j.solener.2005.03.010>
- Kong, F., Sun, C., Liu, F., Yin, H., Jiang, F., Pu, Y., Cavan, G., Skelhorn, C., Middel, A., & Dronova, I. (2016). Energy saving potential of fragmented green spaces due to their temperature regulating ecosystem services in the summer. *Applied Energy*, 183, 1428–1440. <https://doi.org/10.1016/j.apenergy.2016.09.070>
- Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, 15(3), 259–263. <https://doi.org/10.1127/0941-2948/2006/0130>
- Lauzet, N., Rodler, A., Musy, M., Azam, M. H., Guernouti, S., Mauree, D., & Colinart, T. (2019). How building energy models take the local climate into account in an urban context – A review. *Renewable and Sustainable Energy Reviews*, 116(October), 109390. <https://doi.org/10.1016/j.rser.2019.109390>
- Li, X., Zhou, Y., Yu, S., Jia, G., Li, H., & Li, W. (2019). Urban heat island impacts on building energy consumption: A review of approaches and findings. *Energy*, 174, 407–419. <https://doi.org/10.1016/j.energy.2019.02.183>
- Lim, H., & Zhai, Z. J. (2017). Review on stochastic modeling methods for building stock energy prediction. *Building Simulation*, 10(5), 607–624. <https://doi.org/10.1007/s12273-017-0383-y>

- Llewelyn Davies Yeang. (2009). *Urban design compendium*. Homes and communities agency
- Mackay, D. (2008). *Sustainable energy – without the hot air*. UIT Cambridge. ISBN 978-0-9544529-3-3. Available free online from www.withouthotair.com.
- Manaugh, K., & Kreider, T. (2013). *What is mixed use ? Presenting an interaction method for measuring land use mix*. 63–72. <https://doi.org/10.5198/jtlu.v6i1.291>
- Mangan, S. D., & Koçlar Oral, G. (2020). Impacts of future weather data on the energy performance of buildings in the context of urban geometry. *Cogent Engineering*, 7(1). <https://doi.org/10.1080/23311916.2020.1714112>
- Mangan, S. D., Oral, G. K., Sozen, I., & Kocagil, I. E. (2020). Evaluation of settlement textures in terms of building energy , economic performance , and outdoor thermal comfort. *Sustainable Cities and Society*, 56(October 2019), 102110. <https://doi.org/10.1016/j.scs.2020.102110>
- Marshall, S., & Çalışkan, O. (2011). A joint framework for urban morphology and design. *Built Environment*, 37(4), 409–426. <https://doi.org/10.2148/benv.37.4.409>
- Marshall, S., Gong, Y., & Green, N. (2010). *Urban Compactness : Indicators of a Property Distinct from Density Urban Compactness : Indicators of a Property Distinct from Density*.
- Martin, L., & March, L. (1972). *Urban space and structures*; Cambridge University Press
- Martin, M., Wong, N. H., Hii, D. J. C., & Ignatius, M. (2017). Comparison between simplified and detailed EnergyPlus models coupled with an urban canopy model. *Energy and Buildings*, 157, 116–125. <https://doi.org/10.1016/j.enbuild.2017.01.078>
- Martinez-moyano, I. J. (2011). *Modeling the Commercial Buildings Sector : an*

Agent-based Approach. January.

- Martins, T. A. de L., Adolphe, L., Bastos, L. E. G., & Martins, M. A. de L. (2016). Sensitivity analysis of urban morphology factors regarding solar energy potential of buildings in a Brazilian tropical context. *Solar Energy*, 137, 11–24. <https://doi.org/10.1016/j.solener.2016.07.053>
- Mauree, D., Coccolo, S., Kaempf, J., & Scartezzini, J.-L. (2017). *Multi-scale modelling to evaluate building energy consumption at the neighbourhood scale*. <https://doi.org/10.5281/zenodo.847291.Funding>
- Mauree, D., Naboni, E., Coccolo, S., Perera, A. T. D., Nik, V. M., & Scartezzini, J. L. (2019). A review of assessment methods for the urban environment and its energy sustainability to guarantee climate adaptation of future cities. *Renewable and Sustainable Energy Reviews*, 112(May), 733–746. <https://doi.org/10.1016/j.rser.2019.06.005>
- McKeen, P., & Fung, A. S. (2014). *The Effect of Building Aspect Ratio on Energy Efficiency* : 336–354. <https://doi.org/10.3390/buildings4030336>
- Meadowcroft, J. (2007). Who is in charge here? Governance for sustainable development in a complex world. *Journal of Environmental Policy and Planning*, 9(3–4), 299–314. <https://doi.org/10.1080/15239080701631544>
- Méndez Echenagucia, T., Capozzoli, A., Cascone, Y., & Sassone, M. (2015). The early design stage of a building envelope: Multi-objective search through heating, cooling and lighting energy performance analysis. *Applied Energy*, 154, 577–591. <https://doi.org/10.1016/j.apenergy.2015.04.090>
- Miao, C., Yu, S., Hu, Y., Zhang, H., & He, X. (2020). Review of methods used to estimate the sky view factor in urban street canyons. *Building and Environment*, 168(72), 106497. <https://doi.org/10.1016/j.buildenv.2019.106497>
- Miller, W., & Buys, L. (2012). Positive-energy homes: Impacts on, and implications for, ecologically sustainable urban design. *Urban Design International*, 17(1),

45–61. <https://doi.org/10.1057/udi.2011.20>

MIT & Tsingua Univesity. (2010). *New Approaches to Urban Design and Energy Performance*.

MoEU (Ministry of Environment and Urbanization). (2018). *Turkish Building Sector Energy Efficiency Technology Atlas* (Issue June). <https://www.ee-turkey.org/news/publication-energy-efficiency-technology-atlas-turkeys-building-sector-may-2018>

Mohajeri, N., Upadhyay, G., Gudmundsson, A., Assouline, D., Kämpf, J., & Scartezzini, J. L. (2016). Effects of urban compactness on solar energy potential. *Renewable Energy*, 93, 469–482. <https://doi.org/10.1016/j.renene.2016.02.053>

Monteiro, C. S., Pina, A., Cerezo, C., Reinhart, C., & Ferrão, P. (2017). The Use of Multi-detail Building Archetypes in Urban Energy Modelling. *Energy Procedia*, 111(September 2016), 817–825. <https://doi.org/10.1016/j.egypro.2017.03.244>

Morille, B., Lauzet, N., & Musy, M. (2015). SOLENE-microclimate : a tool to evaluate envelopes efficiency on energy consumption at district scale . *Energy Procedia*, 78, 1165–1170. <https://doi.org/10.1016/j.egypro.2015.11.088>

Naboni, E., Natanian, J., Brizzi, G., Florio, P., Chokhachian, A., Galanos, T., & Rastogi, P. (2019). A digital workflow to quantify regenerative urban design in the context of a changing climate. *Renewable and Sustainable Energy Reviews*, 113(July), 109255. <https://doi.org/10.1016/j.rser.2019.109255>

Nakano, A. (2015). *Urban Weather Generator User Interface Development: Towards a Usable Tool for Integrating Urban Heat Island Effect within Urban Design Process*.

NASA. (2019). The Causes of Climate Change. *Gateway to the United Nations Systems Work On Climate Change*, 2019(04 October 2019), 1–8.

- Natanian, J. (2020). *Beyond Zero Energy Districts a Holistic Energy and Environmental Quality Evaluation*. Technical University of Munich.
- Natanian, J., Aleksandrowicz, O., & Auer, T. (2019a). A parametric approach to optimizing urban form, energy balance and environmental quality: The case of Mediterranean districts. *Applied Energy*, 254(August), 113637. <https://doi.org/10.1016/j.apenergy.2019.113637>
- Natanian, J., Aleksandrowicz, O., & Auer, T. (2019b). A parametric approach to optimizing urban form , energy balance and environmental quality : The case of Mediterranean districts. *Applied Energy*, 254(November 2018), 113637. <https://doi.org/10.1016/j.apenergy.2019.113637>
- Natanian, J., Maiullari, D., Yeziro, A., & Auer, T. (2019). Synergetic urban microclimate and energy simulation parametric workflow. *Journal of Physics: Conference Series*, 1343(1). <https://doi.org/10.1088/1742-6596/1343/1/012006>
- Nault, E., Peronato, G., Rey, E., & Andersen, M. (2015). Review and critical analysis of early-design phase evaluation metrics for the solar potential of neighborhood designs. *Building and Environment*, 92, 679–691. <https://doi.org/10.1016/j.buildenv.2015.05.012>
- Newman, P., & Kenworthy, J. (2006). *Newmankenworthyurbandesign.Pdf*. 2(1).
- Newman, P., & Kenworthy, J.R. (2015). *The End of Automobile Dependence : How Cities Are Moving Beyond Car-Based Planning*. Island Press.
- Newman, P., Dr., & Kenworthy, J. R. (1999). *Sustainability and cities : overcoming automobile dependence*. Island Press.
- Ng, E., Chen, L., Wang, Y., & Yuan, C. (2012). A study on the cooling effects of greening in a high-density city : An experience from Hong Kong. *Building and Environment*, 47, 256–271. <https://doi.org/10.1016/j.buildenv.2011.07.014>
- Nouvel, R., Duminil, E., & Coors, V. (2015). *SIMSTADT , a New Workflow-driven Urban Energy Simulation Platform for CityGML City Models SIMSTADT , A*

*NEW WORKFLOW-DRIVEN URBAN ENERGY SIMULATION PLATFORM
FOR CITYGML CITY MODELS. September.*

- Oh, M., & Kim, Y. (2019). Identifying urban geometric types as energy performance patterns. *Energy for Sustainable Development*, 48, 115–129. <https://doi.org/10.1016/j.esd.2018.12.002>
- Oke, T.. (1973). City Size and the Urban Heat Island. *Atmospheric Environment* (1967). 7. 769-779. 10.1016/0004-6981(73)90140-6.
- Oke, T.R. (1981), Canyon geometry and the nocturnal urban heat island: Comparison of scale model and field observations. *J. Climatol.*, 1: 237-254. doi:[10.1002/joc.3370010304](https://doi.org/10.1002/joc.3370010304)
- Oke, T. R. (1995). Wind Climate in Cities. *Wind Climate in Cities*, December. <https://doi.org/10.1007/978-94-017-3686-2>
- Oliveira, V. (2016). *Urban morphology: an introduction to the study of the physical form of cities*. Springer.
- Olofsson, T., Meier, A., & Lamberts, R. (2004). Rating the Energy Performance of Buildings. *International Journal*, 3(2004), 18. <http://escholarship.org/uc/item/52j7d39x>
- OWENS, S., & RICKABY, P. (1983). Energy and the Pattern of Human Settlements. *Built Environment* (1978-), 9(2), 150-159. Retrieved August 16, 2020, from www.jstor.org/stable/23284810
- Owens, S. E. (1986). *Energy, planning, and urban form*. Pion.
- Owens, S. E. (1992). Land-use planning for energy efficiency. *Applied Energy*, 43(1-3), 81-114.
- Ouhajjou, N. (2016). *Ontology based decision support in urban energy planning*. Wien.
- Ouyang, W., Morakinyo, T. E., Ren, C., & Ng, E. (2020). The cooling efficiency of

- variable greenery coverage ratios in different urban densities: A study in a subtropical climate. *Building and Environment*, 174(February), 106772. <https://doi.org/10.1016/j.buildenv.2020.106772>
- Öztürk, M. Z., Çetinkaya, G., & Aydın, S. (2017). Türkiye’de İç Göçlerin Toplumsal Yapıda Neden Olduğu Değişimler, Meydana Getirdiği Sorunlar ve Çözüm Önerileri. *Journal of Geography*, 35. <https://doi.org/10.26650/jgeog330955>
- Pacheco, R., Ordóñez, J., & Martínez, G. (2012). *Energy efficient design of building : A review*. 16, 3559–3573. <https://doi.org/10.1016/j.rser.2012.03.045>
- Pacheco, R., Ordóñez, J., & Martínez, G. (2012). Energy efficient design of building: A review. *Renewable and Sustainable Energy Reviews*, 16(6), 3559–3573. <https://doi.org/10.1016/j.rser.2012.03.045>
- Páez, A. (2010). Energy-urban transition: The Mexican case. *Energy Policy*, 38(11), 7226–7234. <https://doi.org/10.1016/j.enpol.2010.07.053>
- Patterson, M. G. (1996). *What is energy efficiency? Concepts , indicators and methodological issues*. 24(5), 377–390.
- Peker, Z. (2005). Integrating renewable energy technologies into cities through urban planning: In the case of geothermal and wind energy.
- Polly, B., Kutscher, C., Macumber, D., Schott, M., Pless, S., Livingood, B., & Geet, O. Van. (2016). *From Zero Energy Buildings to Zero Energy Districts*. September.
- Pont, M. B., & Haupt, P. (2005). *The Spacemate :Density and the Typomorphology of the Urban Fabric*. November, 55–68.
- Pont, M. B., & Haupt, P. E. R. (2009). *Space, Density and Urban Form*.
- Poon, K. H., Kämpf, J. H., Tay, S. E. R., Wong, N. H., & Reindl, T. G. (2020). Parametric study of URBAN morphology on building solar energy potential in Singapore context. *Urban Climate*, 33(April 2019), 100624.

<https://doi.org/10.1016/j.uclim.2020.100624>

Ratti, C., Baker, N., & Steemers, K. (2005). Energy consumption and urban texture. *Energy and Buildings*, 37(7), 762–776. <https://doi.org/10.1016/j.enbuild.2004.10.010>

Ratti, C., Raydan, D., & Steemers, K. (2003). Building form and environmental performance: Archetypes, analysis and an arid climate. *Energy and Buildings*, 35(1), 49–59. [https://doi.org/10.1016/S0378-7788\(02\)00079-8](https://doi.org/10.1016/S0378-7788(02)00079-8)

Ratti, C., & Richens, P. (2004). *Raster analysis of urban form*. 31(1), 297–310. <https://doi.org/10.1068/b2665>

Real Estate Research Corporation (1974). The Costs of Sprawl: Environmental and Economic Costs of Alternative Residential Development Patterns at the Urban Fringe. Portland Regional Planning History. Paper 26. http://pdxscholar.library.pdx.edu/oscdl_planning/26

Reinhart, C. F., & Davila, C. C. (2016). Urban building energy modeling e A review of a nascent field. *Building and Environment*, 97, 196–202. <https://doi.org/10.1016/j.buildenv.2015.12.001>

Reinhart, C. F., Timur Dogan, Jakubiec, J. A., Rakha, T., & Sang, A. (2013). *UMI - AN URBAN SIMULATION ENVIRONMENT FOR BUILDING ENERGY USE , DAYLIGHTING AND WALKABILITY* Christoph F Reinhart , Timur Dogan , J Alstan Jakubiec , Tarek Rakha and Andrew Sang Massachusetts Institute of Technology Department of Architecture. 476–483.

Remmen, P., Lauster, M., Mans, M., Fuchs, M., Müller, D., Remmen, P., Lauster, M., Mans, M., & Fuchs, M. (2018). *TEASER : an open tool for urban energy modelling of building stocks*. 1493. <https://doi.org/10.1080/19401493.2017.1283539>

REN21, 2019 a. Renewables in Cities 2019 Global Status Report (Paris: REN21 Secretariat) ISBN: 978-3-9818911-9-5

- REN21. 2019 b. Renewables 2019 Global Status Report (Paris: REN21 Secretariat). ISBN 978-3-9818911-7-1
- Robinson, D. (2006). *Urban morphology and indicators of radiation availability*. 80, 1643–1648. <https://doi.org/10.1016/j.solener.2006.01.007>
- Robinson, D., Haldi, F., Kämpf, J., Leroux, P., Perez, D., Rasheed, A., & Wilke, U. (2009). *CITYSIM: COMPREHENSIVE MICRO-SIMULATION OF RESOURCE FLOWS FOR SUSTAINABLE URBAN PLANNING*. 1083–1090.
- Sağlam, N. G., Yılmaz, A. Z., Gali, G., & Bonab, T. A. (2016). *Reference Building Establishment Procedure for the Residential Buildings in Turkey*. January.
- Sailor, D. J. (2011). A review of methods for estimating anthropogenic heat and moisture emissions in the urban environment. *International Journal of Climatology*, 31(2), 189–199. <https://doi.org/10.1002/joc.2106>
- Salat, S., & Bourdic, L. (2015). *Urban Complexity, Efficiency and Resilience*. March 2012. <https://doi.org/10.5772/38599>
- Salom, J., Marszal, A. J., Candanedo, J., Widén, J., Byskov Lindberg, K., & Sartori, I. (2014). *Analysis of Load Match and Grid Integration Indicators in Net Zero Energy Buildings with High-Resolution Data. A report of Subtask A IEA Task 40/Annex 52 Towards Net Zero Energy Solar Buildings*. (Issue March). <https://www.iea-shc.org/Data/Sites/1/publications/T40A52--LMGI-in-Net-ZEBs--STA-Technical-Report.pdf>
- Samuelson, H., Claussnitzer, S., Goyal, A., Chen, Y., & Romo-Castillo, A. (2016). Parametric energy simulation in early design: High-rise residential buildings in urban contexts. *Building and Environment*, 101, 19–31. <https://doi.org/10.1016/j.buildenv.2016.02.018>
- Santamouris, M., & Asimakopoulos, D. N. (2001). *Energy and climate in the urban built environment*. James X James
- Santamouris, M. (2020). Recent progress on urban overheating and heat island

- research. Integrated assessment of the energy, environmental, vulnerability and health impact. Synergies with the global climate change. *Energy and Buildings*, 207. <https://doi.org/10.1016/j.enbuild.2019.109482>
- Santamouris, M., Cartalis, C., Synnefa, A., & Kolokotsa, D. (2015). On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings - A review. *Energy and Buildings*, 98, 119–124. <https://doi.org/10.1016/j.enbuild.2014.09.052>
- Sarralde, J. J., Quinn, D. J., Wiesmann, D., & Steemers, K. (2015). Solar energy and urban morphology: Scenarios for increasing the renewable energy potential of neighbourhoods in London. *Renewable Energy*, 73, 10–17. <https://doi.org/10.1016/j.renene.2014.06.028>
- Sattrup, P. A., & Strømman-Andersen, J. (2013). Building typologies in northern European cities: daylight, solar access, and building energy use. *Journal of Architectural and Planning Research*, 56-76.
- Schimschar, S., Boermans, T., Kretschmer, D., Offermann, M., & John, A. (2016). *U-Value maps Turkey for cost-optimality in the context of the EPBD Final report U-Value maps Turkey Applying the comparative methodology framework*. www.ecofys.com
- Schönwandt, W. (2019). Solving Complex Problems: Applying a Problem-Oriented Approach to the Case of the Orient/ East-Med Corridor. In B. Scholl, A. Perić, & M. Niedermaier (Eds.), *Spatial and Transport Infrastructure Development in Europe: Example of the Orient/East-Med Corridor* (pp. 71-90). Hannover: Verl. d. ARL. <https://nbn-resolving.org/urn:nbn:de:0168-ssoar-66484-1>
- Sharifi, A. (2020). Co-benefits and synergies between urban climate change mitigation and adaptation measures: A literature review. *Science of The Total Environment*, 750, 141642. <https://doi.org/10.1016/j.scitotenv.2020.141642>
- Sharifi, Ayyoob. (2020). Trade-offs and conflicts between urban climate change mitigation and adaptation measures: A literature review. *Journal of Cleaner*

Production, 276. <https://doi.org/10.1016/j.jclepro.2020.122813>

- Silva, M., Oliveira, V., & Leal, V. (2017). Urban Form and Energy Demand: A Review of Energy-relevant Urban Attributes. *Journal of Planning Literature*, 32(4), 346–365. <https://doi.org/10.1177/0885412217706900>
- Soares, N., Bastos, J., Pereira, L. D., Soares, A., Amaral, A. R., Asadi, E., Rodrigues, E., Lamas, F. B., Monteiro, H., Lopes, M. A. R., & Gaspar, A. R. (2017). A review on current advances in the energy and environmental performance of buildings towards a more sustainable built environment. *Renewable and Sustainable Energy Reviews*, 77(February), 845–860. <https://doi.org/10.1016/j.rser.2017.04.027>
- Steadman, P. (1975). *Energy, environment and building*. Cambridge University Press.
- Steemers, K. (2003). Energy and the city: density, buildings and transport. *Energy and buildings*, 35(1), 3-14.
- Strømman-Andersen, J., & Sattrup, P. A. (2011). The urban canyon and building energy use: Urban density versus daylight and passive solar gains. *Energy and Buildings*, 43(8), 2011–2020. <https://doi.org/10.1016/j.enbuild.2011.04.007>
- Swan, L. G., & Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and Sustainable Energy Reviews*, 13(8), 1819–1835. <https://doi.org/10.1016/j.rser.2008.09.033>
- Takebayashi, H., Ishii, E., Moriyama, M., Sakaki, A., Nakajima, S., & Ueda, H. (2015). Study to examine the potential for solar energy utilization based on the relationship between urban morphology and solar radiation gain on building rooftops and wall surfaces. *Solar Energy*, 119, 362–369. <https://doi.org/10.1016/j.solener.2015.05.039>
- Taleghani, M., Tenpierik, M., Dobbels, A. Van Den, & Dear, R. De. (2013).

- Energy use impact of and thermal comfort in different urban block types in the Netherlands. *Energy & Buildings*, 67, 166–175. <https://doi.org/10.1016/j.enbuild.2013.08.024>
- The Bancroft Library, B. E. (2011). 1973-74 Oil Crisis - Timeline - Slaying the Dragon of Debt - Regional Oral History Office - University of California, Berkeley. <https://bancroft.berkeley.edu/ROHO/projects/debt/oilcrisis.html>
- Theeuwes, N. E., Steeneveld, G. J., Ronda, R. J., Heusinkveld, B. G., van Hove, L. W. A., & Holtslag, A. A. M. (2014). Seasonal dependence of the urban heat island on the street canyon aspect ratio. *Quarterly Journal of the Royal Meteorological Society*, 140(684), 2197–2210. <https://doi.org/10.1002/qj.2289>
- Tsai, Y. H. (2005). Quantifying urban form: Compactness versus “sprawl.” *Urban Studies*, 42(1), 141–161. <https://doi.org/10.1080/0042098042000309748>
- Turkish Standard, T. S. (2013). 825 Thermal insulation requirements for buildings
- Unger, R. (2013). Energy Transitions in History: Global Cases of Continuity and Change (= RCC Perspectives 2013/2).
- United Nations, Department of Economic and Social Affairs, Population Division (2019). World Urbanization Prospects 2018: Highlights (ST/ESA/SER.A/421).
- United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019: Highlights (ST/ESA/SER.A/423).
- Urban Task Force. (2005). *Towards an Urban Renaissance*.
- van den Hoek, J. W. (2008). *century texture and most likely one will end up with counting only jobs or only beds as is shown in figure 1. Florida*, 1–12.
- Vandevyvere, H., & Stremke, S. (2012). *Urban Planning for a Renewable Energy Future: Methodological Challenges and Opportunities from a Design Perspective. December*. <https://doi.org/10.3390/su4061309>
- Vartholomaïos, A. (2017). A parametric sensitivity analysis of the influence of urban

- form on domestic energy consumption for heating and cooling in a Mediterranean city. *Sustainable Cities and Society*, 28, 135–145. <https://doi.org/10.1016/j.scs.2016.09.006>
- Verbong, G. P. J., & Loorbach, D. (Eds.) (2012). *Governing the energy transition : reality, illusion or necessity?* (Routledge studies in sustainability transitions; Vol. 4). Routledge Taylor & Francis Group.
- Wall, M., Snow, M., Dahlberg, J., Lundgren, M., Lindkvist, C., Lobaccaro, G., Siems, T., Simon, K., & Probst, M. C. M. (2017). Urban planning for solar energy - IEA SHC TASK 51. *ISES Solar World Congress 2017 - IEA SHC International Conference on Solar Heating and Cooling for Buildings and Industry 2017, Proceedings*, 2401–2412. <https://doi.org/10.18086/swc.2017.37.06>
- Wang, L., Long, R., Chen, H., Li, W., & Yang, J. (2019). A review of studies on urban energy performance evaluation. *Environmental Science and Pollution Research*, 26(4), 3243–3261. <https://doi.org/10.1007/s11356-018-3915-9>
- Watkins, R., Palmer, J., & Kolokotroni, M. (2007). Increased temperature and intensification of the urban heat island: Implications for human comfort and urban design. *Built Environment*, 33(1), 85–96. <https://doi.org/10.2148/benv.33.1.85>
- Wong, N. H., Jusuf, S. K., Syafii, N. I., Chen, Y., Hajadi, N., Sathyanarayanan, H., & Manickavasagam, Y. V. (2011). Evaluation of the impact of the surrounding urban morphology on building energy consumption. *Solar Energy*, 85(1), 57–71. <https://doi.org/10.1016/j.solener.2010.11.002>
- Wong, N. H., Tan, C. L., Kolokotsa, D. D., & Takebayashi, H. (2021). Greenery as a mitigation and adaptation strategy to urban heat. *Nature Reviews Earth & Environment*, 2(3), 166–181. <https://doi.org/10.1038/s43017-020-00129-5>
- World Commission on Environment and Development (WCED) (1987). *Our Common Future* (New York: Oxford University)

- Wu, Z., & Ren, Y. (2019). A bibliometric review of past trends and future prospects in urban heat island research from 1990 to 2017. *Environmental Reviews*, 27(2), 241–251. <https://doi.org/10.1139/er-2018-0029>
- Yin, C., Yuan, M., Lu, Y., Huang, Y., & Liu, Y. (2018). Science of the Total Environment Effects of urban form on the urban heat island effect based on spatial regression model. *Science of the Total Environment*, 634, 696–704. <https://doi.org/10.1016/j.scitotenv.2018.03.350>
- Yu, C., & Pan, W. (2018). *EFFECTS OF SHADING ON THE ENERGY CONSUMPTION OF HIGH-RISE OFFICE BUILDINGS IN HONG KONG* Cong Yu and Wei Pan Department of Civil Engineering , The University of Hong Kong , Hong Kong Corresponding email : yucong@hku.hk. 2012, 486–493.
- Yuan, C., Chen, L., Yuan, C., & Chen, L. (2011). *density cities based on sky view factor and urban Kong Mitigating urban heat island effects in high- density cities based on sky view factor and urban morphological understanding : a study of Hong Kong*. 8628. <https://doi.org/10.1080/00038628.2011.613644>
- Zhang, B., Xie, G., Gao, J., & Yang, Y. (2014). The cooling effect of urban green spaces as a contribution to energy-saving and emission-reduction : A case study in Beijing , China. *Building and Environment*, 76, 37–43. <https://doi.org/10.1016/j.buildenv.2014.03.003>
- Zhang, J., Wong, N. H., & HII, D. J. C. (2015). *THE RELATIONSHIP BETWEEN BUILDING FORM TYPOLOGY AND COOLING*.
- Zhang, J., Xu, L., Shabunko, V., En, S., Tay, R., Sun, H., Siu, S., Lau, Y., & Reindl, T. (2019). *Impact of urban block typology on building solar potential and energy use efficiency in tropical high-density city*. 240(January), 513–533. <https://doi.org/10.1016/j.apenergy.2019.02.033>
- Zhang, J., Xu, L., Shabunko, V., Tay, S. E. R., Sun, H., Lau, S. S. Y., & Reindl, T. (2019). Impact of urban block typology on building solar potential and energy

use efficiency in tropical high-density city. *Applied Energy*, 240(February), 513–533. <https://doi.org/10.1016/j.apenergy.2019.02.033>

Zhang, L., Hong, J., Nasri, A., & Shen, Q. (2012). *How built environment affects travel behavior : A comparative analysis of the connections between land use and vehicle miles traveled in US cities.* 40–52. <https://doi.org/10.5198/jtlu.v5i3.266>

Zhang, X., Lovati, M., Vigna, I., Widén, J., Han, M., Gal, C., & Feng, T. (2018). A review of urban energy systems at building cluster level incorporating renewable-energy-source (RES) envelope solutions. *Applied Energy*, 230(June 2018), 1034–1056. <https://doi.org/10.1016/j.apenergy.2018.09.041>

Zhao, P., Diao, J., & Li, S. (2017). The influence of urban structure on individual transport energy consumption in China's growing cities. *Habitat International*, 66, 95–105. <https://doi.org/10.1016/j.habitatint.2017.06.001>

Zhu, P., Yan, D., Sun, H., Huang, Y., & Jin, Y. (2018). *Study on Energy Performance of Passive Zone and Non-passive Zone in Office Study on Energy Performance of Passive Zone and Non-passive Zone in Office Buildings.* December.