COMPARATIVE ENERGY SIMULATION FOR HIGH-RISE RESIDENTIAL BUILDING ENVELOPE MATERIALS: HEATING AND COOLING EFFICIENCY ANALYSES

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COMPARATIVE ENERGY SIMULATION FOR HIGH-RISE RESIDENTIAL BUILDING ENVELOPE MATERIALS: HEATING AND COOLING EFFICIENCY ANALYSES

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To my beloved family, and my dearest friends

Thank you for your endless love, trust, and support.

ABSTRACT

The interest in building energy performance and efficiency has been increasing in the last decades. Although several studies on energy-efficient buildings exist in the architecture, engineering, and construction (AEC) literature, none of them addressees the heating and cooling performance of high-rise building envelope materials. Such research would be a valuable guideline for the early decision-making process in energy-efficient high-rise building design. This study aims to (1) build up a knowledge base for exploring the optimal building envelope components based on the relevant aspects of energy performance to design energy-efficient high-rise buildings and (2) analyze and compare the effects of three different building envelope materials (i.e., reinforce concrete, timber wall, and curtain wall) on energy performance of a high-rise residential building. For this purpose, first, Cite Space, VoSViewer, and Gephi were used for building up a knowledge base in building energy performance. Then, various scenarios for evaluating the impact of envelope components (e.g., wall structure, window-to-wall ratio, and site orientation) were developed and analyzed. Efficient scenarios were opted for developing analyses in terms of floor, roof, and glazing type to decrease the heat loss/gain in the roof, floor, and glazing. Design Builder was utilized to design and model the case study building based in Istanbul, Turkey, and perform energy analysis for its heating and cooling efficiency by focusing on walls, roof, and ceiling (considering the building's orientation), window-to-wall ratio (WWR), and insulation. This research contributes to the AEC literature and industry by providing (1) detailed information about influential factors in heat loss/gain, (2) the factors to achieve energy efficiency and to decrease heating and cooling demand in high-rise buildings, (3) combinations for energy efficient building envelope materials, and (4) knowledge base for an efficient heating ventilation air conditioning system design for high-rise residential buildings. Accordingly, the results would be very useful for assisting professionals in the decision-making process of energy-efficient high-rise residential building design. Further, this study reveals promising topics in this scope for future research.

Keywords: Energy performance, energy efficiency, building envelope, high-rise building, Design Builder, heating analysis, cooling analysis

ÖZETÇE

Binaların enerji performansına ve verimliliğine yönelik ilgi son yıllarda artmaktadır. Mimarlık, mühendislik ve inşaat (AEC) literatüründe enerji verimli binalar üzerine çeşitli çalışmalar olmasına rağmen, bunların hiçbiri yüksek bina kabuğu malzemelerinin ısıtma ve soğutma performansını ele almamaktadır. Böyle bir araştırma, enerji verimli yüksek bina tasarımında erken karar verme süreci için değerli bir kılavuz olacaktır. Bu çalışma, (1) enerji verimli yüksek binalar tasarlamak için enerji performansının ilgili yönlerine dayalı optimal bina kabuğu bileşenlerini keşfetmek için bir bilgi tabanı oluşturmayı ve (2) yüksek katlı bir konut binasının üç farklı bina kabuğunun (yani, betonarme, ahşap duvar ve perde duvar) etkilerini enerji performansı üzerine malzemeler analiz etmeyi ve karşılaştırmayı hedeflemektedir. Bu amaçla, bina enerji performansında bir bilgi tabanı oluşturmak için ilk olarak Cite Space, VOSViewer ve Gephi kullanılmıştır. Daha sonra, zarf bileşenlerinin etkisini değerlendirmek için çeşitli senaryolar (ör. duvar yapısı, pencere-duvar oranı ve saha yönelimi) geliştirilmiş ve analiz edilmiştir. Çatı, döşeme ve camdaki ısı kayıp/kazanımını azaltmak için zemin, çatı ve cam tipi bazında analizler geliştirmek için verimli senaryolar tercih edilmiştir. Design Builder, Istanbul, Turkiye'de olan vaka çalışması binasını tasarlamak ve modellemek ve duvarlara, çatıya ve tavana (binanın yönelimi dikkate alınarak), pencerenin duvara oranına odaklanarak binanın ısıtma ve soğutma verimliliği için enerji analizi yapmak amacıyla kullanılmıştır. Bu araştırma, (1) ısı kayıp/kazancındaki etkili faktörler, (2) yüksek binalarda enerji verimliliğini sağlayan ve ısıtma ve soğutma talebini azaltan faktörler, (3) enerji açısından verimli bina kaplama malzemeleri için kombinasyonlar ve (4) yüksek katlı konut binaları için verimli bir Isıtma Havalandırma Klima Sistemi tasarımı için bilgi tabanı hakkında ayrıntılı bilgi sağlayarak AEC literatürüne ve

endüstrisine katkıda bulunmaktadır. Buna göre, sonuçlar, enerji verimli yüksek katlı konut bina tasarımının karar verme sürecinde profesyonellere yardımcı olmak için çok faydalı olacaktır. Ayrıca bu çalışma, gelecekte yapılacak araştırmalar için bu kapsamda umut vaat eden konuları ortaya koymaktadır.

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TABLE OF CONTENTS

ABSTRACT .... **iv**

ÖZETÇE .... **vi**

ACKNOWLEDGMENTS .... **viii**

TABLE OF CONTENTS .... **ix**

LIST OF TABLES .... **xi**

LIST OF FIGURES .... **xii**

I INTRODUCTION **1**

1.1 Global energy state 1

1.1.1 Paris Agreement and Building Energy Consumption 2

1.1.2 Energy Efficient Building with Passive Design Approach 4

1.1.3 Turkey Energy State 6

1.1.4 Building Envelope and Effective Factors 7

1.2 The Background of Energy Performance and Energy Efficiency in Literature 9

1.2.1 Research Gap 10

1.2.2 Research Objective 14

1.3 Thesis outline: 15

II METHODOLOGY **16**

2.1 Scientometric analysis 16

2.1.1 Scientometric Techniques 17

2.1.1.1 Metrics and Properties in Scientometric Analysis 18

2.1.1.2 Metrics and Properties in Scientometric Analysis 19

2.1.1.3 Betweenness Centrality 19

2.1.1.4 Modularity and Mean Silhouette 19

2.2 Systematic Literature Review 20

2.3 Design Builder 22
2.4 Case study 22
2.5 Climate Zone 24
2.6 Simulation criteria for cooling analysis: 25

III LITERATURE REVIEW 29

3.1 Keyword Co-occurrence 31
3.2 Keyword Burst 40
3.3 Keyword Co-Occurrence Cluster Analysis 44
3.4 Findings of Scientometric analysis 51
3.5 Research Background of Building Energy Efficiency 51

IV RESEARCH RESULTS AND DISCUSSION 54

4.1 Heating Analyses 54
4.2 Cooling Analyses 63
4.2.1 Cooling Analysis of Reference Building 64
4.2.2 Cooling Analysis of Curtain Wall 68
4.2.3 Cooling Analysis of Curtain Wall 72

V CONCLUSIONS 76

VI CONTRIBUTIONS AND FUTURE WORK 79

APPENDIX A 80

REFERENCES 90

VITA 106

PUBLICATIONS 107

LIST OF TABLES

Table 1. Direction and impact of wind 25

Table 2. Setup details for the activity tab to implement simulation 26

Table 3. Reference building design criteria for the cooling analysis 28

Table 4. Keywords influence energy performance in AEC 35

Table 5. Top 42 keywords with the most robust citation burst 42

Table 6. The top keywords cluster 50

Table 7. Envelope component for the reference building 65

LIST OF FIGURES

Figure 1. The amount of building and construction industry energy consumption and carbon emission, retrieved from Sources: (IEA 2020d; IEA 2020b) and adapted from “IEA World Energy Statistics and Balances” and “Energy Technology Perspectives"[9]. 2

Figure 2. Energy consumption breakdown by country adapted from (https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html) [4] 3

Figure 3. The model of the case study building and sun path 23

Figure 4. The stand-alone model for case study building in DesignBuilder 23

Figure 5. Structure of wall components (left picture. curtain wall, the right picture demonstrates timber frame wall super insulated) 24

Figure 6. The wind direction in Istanbul 25

Figure 7. Number of publications on the building energy performance between 2010-2022 in the WoS database 30

Figure 8. Network of keywords co-occurrence analysis 33

Figure 9. Keyword co-occurrence cluster timeline 45

Figure 10. List of co-occurrence keywords 49

Figure 11. Reference building’s scenario heating design analyses results 55

Figure 12. Evaluation of heating design analyses for reference building’s scenario...... 58

Figure 13. Heating analysis of reference building with zero degrees’ site orientation and 40% WWR 57

Figure 14. Curtain wall scenario heating design analyses results 61

Figure 15. Evaluation of heating design analyses for curtain wall’s scenario 60

Figure 16. Timber wall scenario’s heating design analyses results 67

Figure 17. Evaluation of heating design analyses for timber wall’s scenario 68

Figure 18. The result of cooling design analyses for reference building regarding components 69
Figure 19. The results of cooling design analyses of reference buildings regarding temperature 70
Figure 20. The results of cooling design analyses for the reference building 71
Figure 21. The results of cooling design analyses for curtain wall's scenario regarding temperature 72
Figure 22. The results of cooling design analyses for curtain wall's scenario regarding components 73
Figure 23. The results of cooling design analyses for curtain wall 74
Figure 24. The results for cooling design analyses of the curtain wall scenario 75
Figure 25. The results of cooling design analyses for timber wall 75
Figure 26. The results of cooling design analyses for timber walls regarding temperature 73
Figure 27. The results of cooling design analyses for timber wall's scenario regarding components 74
Figure 28. The results for cooling design analyses of timber wall scenario 75

CHAPTER I

INTRODUCTION

1.1.Global energy state

Global energy consumption including coal, oil, electricity, heat, and biomass has grown by approximately 6000 Mtoe (Million Tons of Oil Equivalent) between 1990-2019 years[1]–[3]. Global energy consumption declined regarding COVID, quarantine, and restricted transportation by 4% in 2020, expecting China[4], [5]. Nevertheless, the level of energy consumption is significantly high as well. Decrease in energy consumption achieved significant attention during the last decades in the whole world because of the reduction in the level of energy sources [6]. Meanwhile, one of the side effects of low energy consumption results in lower carbon emissions and a decline in climate change impacts.

Regarding the United Nations Energy reports, buildings are responsible for final energy use by 30-40 percent and 38 percent for CO_2 emission[7]–[9]. According to Figure 1, the construction industry consumes 5% of global energy[10]. Further, the construction industry is a significant energy consumer, accounting for more than a third of global energy consumption[1], [11]. Buildings and construction industries intend to reduce energy consumption and its negative impacts on the natural environment. For this reason, the Paris Agreement has defined a global framework to mitigate the effects of global warming and keep the increase in global average temperature to well below 2°C by limiting CO_2 emissions through improving building energy performance and resilience until 2030[4], [7], [12].

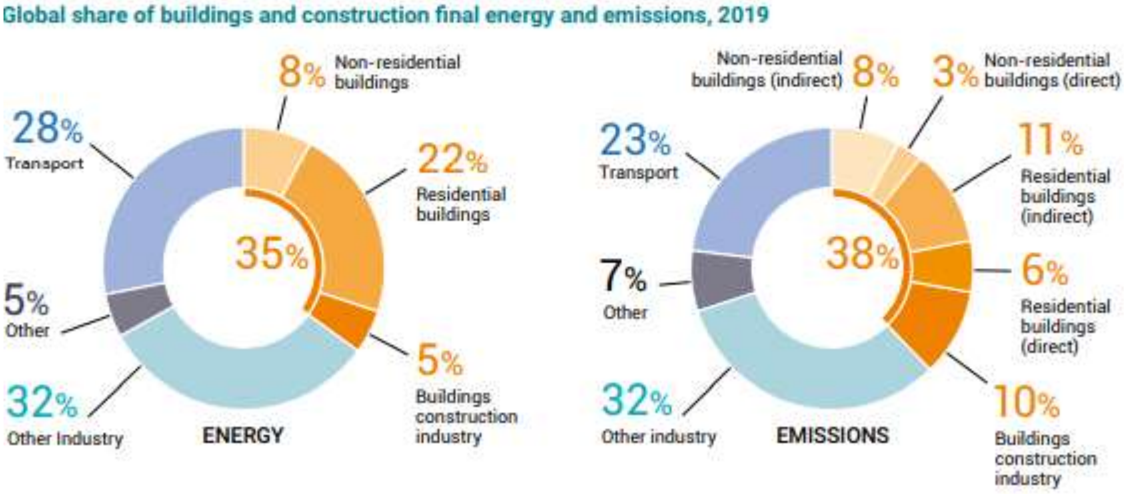


Figure 1. The amount of building and construction industry energy consumption and carbon emission, retrieved from Sources: (IEA 2020d; IEA 2020b) and adapted from "IEA World Energy Statistics and Balances" and "Energy Technology Perspectives"[10].

1.1.1. Paris Agreement and Building Energy Consumption

The Paris Agreement was adopted in December 2015 at the Paris Climate Conference as the first-ever universal, legally valid global climate change agreement (COP21)[13]. The European Union and its international collaborators are among the nearly 190 countries that have signed on to the Paris Agreement. The European Union (EU) formally signed the agreement on October 5, 2016, allowing it to take effect on November 4, 2016. For the agreement to enter into force, at least 55 countries representing at least 55% of global emissions had to deposit their ratification instruments[13]. Meanwhile, Turkey is one of the international collaborators that share in total energy usage of 163 Million Tones (Mtoe) (Figure 2). This amount has increased ranging interval 90-140 Million Tones; approximately 64%. The responsibility of countries is to mitigate loss and damage as well as built resilience to prevent the negative effect of climate change[13].

Building energy consumption in the EU and the US accounted for up to 40% of total global energy demand in 2019[14], while residential and commercial building energy consumption accounts for 36% of total energy consumption in the US, according to the US Department of Energy report [15]. Consequently, buildings and the construction sector are part of this development to mitigate energy demand in buildings and minimize carbon emissions.

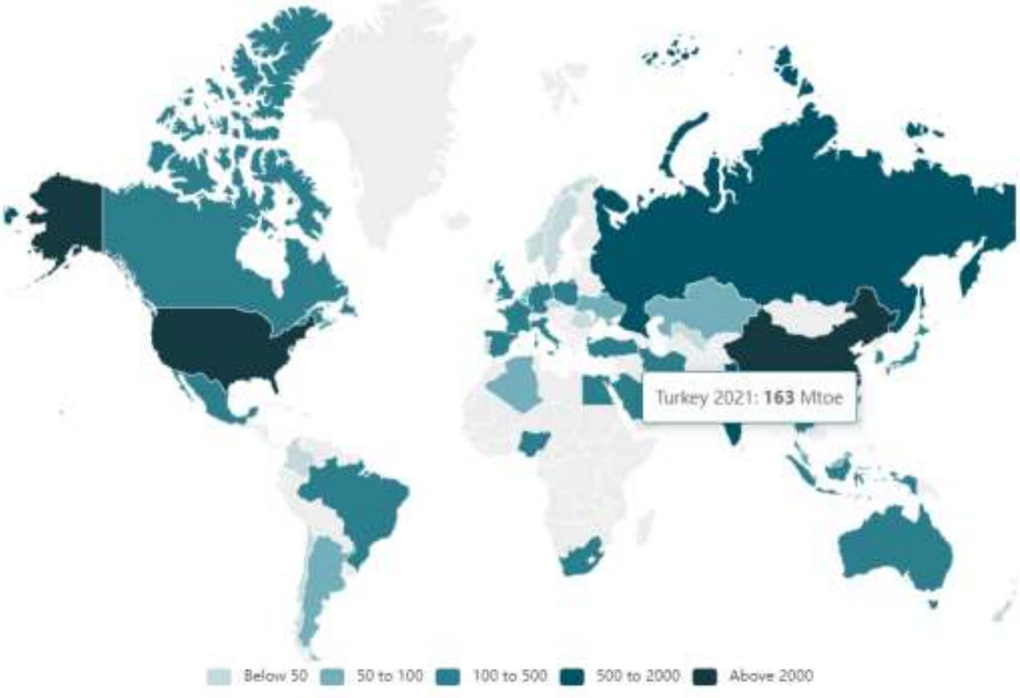


Figure 2. Energy consumption breakdown by country adapted from (https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html) [5]

According to the world energy state, most of the buildings' energy consumption is due to the high amount of heating and cooling demand. Heating and cooling energy demands per floor area were 97.22 (KW/m2) and 33.33 (KW/m2), respectively, according to an International Energy Agency (IEA) report published in 2000[4]. Heating and cooling perform numerous roles in total building energy consumption, ranging from 18% to 73% [16]. Due to global warming, cooling demand is developing while heating demand is declining[17].

1.1.2. Energy Efficient Building with Passive Design Approach

The passive design approach considers site location, material, and building form intending to reduce/remove the need for mechanical cooling, heating, lighting, and ventilation[18]. In addition, passive design strategies include adjusting spatial planning and orientation to regulate solar gains and maximize daylighting, deploying building form and materials to assist natural ventilation strategies, and taking advantage of thermal mass to gain reduction in peak internal temperatures[18].

In the last decades, energy efficacy has gained high interest by developed countries as a solution to adjust the existing condition to provide comfortable conditions with low environmental impact. The method of energy-efficient building is modulating the defined site location, building shape, envelope, materials, and other measures for control throughout the design stage and providing comfort level in the life cycle of the buildings[19]. Therefore, the requirement for implementing an integrated approach is to design a building that can enrich the energy resource efficiency as well as fulfill occupants' demands and decrease energy consumption. To achieve the aforementioned goals, passive building design strategies before the construction stage need to be noticed. The passive strategies focus on utilizing energy-efficient materials, energy-efficient buildings, and integrating renewable energy technologies to improve energy efficiency in the building during its whole life cycle[19]. However, a direct approach in terms of designing a net-zero energy building is not extant but designing a building with low energy consumption could be one of the solutions. Therefore, sustainable development provides the connection between energy consumption and climate[20].

TS825 is the heat insulation regulation of Turkey, which is used to compare the climate and energy consumption[21]. For instance, while fossil fuel is used to fulfill the energy demand for residential buildings, it can be noticed as a negative impact of building on the environment meanwhile not the economic situation. This is the reason to consider the climate situation along with the heating and cooling demand of the building. The calculation of TS825 is based on the surface area to volume ratio[21]. In conclusion, energy performance and climate conditions in buildings impact the energy demand of buildings impressively. Therefore, it is necessary to establish a suitable interaction between climate and energy to gain an energy-efficient building.

According to previous studies, achieving a 50% reduction in energy consumption is possible throughout the integrated design [22]. The logic of integrated design is based on 7 different strategies which are in terms of "*climate condition, decrease heating and cooling demand, reduce lighting load*" by design and utilizing proper envelope and fenestration load[19]. The strategies are listed in detail below:

- Manage heat gain effectively

- ➢ Take advantage of daylight (reduce artificial lighting load, improve visual quality)
- ➢ Provide thermal resistance
- ➢ Provide air circulation through natural ventilation
- ➢ Improve building envelope performance and quality
- ➢ Provide dehumidification, using heat exchange to provide mechanical ventilation
- ➢ Provide energy generation concerning low carbon emission and lower environmental impact[19].

The above-mentioned strategies address ‘ Trias Energetica’ which is composed of three main steps as; energy conservation through design optimization(passive design), sustainable and renewable resources, and energy efficiency[23]. Considering all the mentioned factors, building envelope, material, and building passive design have a high potential to obtain energy efficiency in building and reduce heating and cooling demand.

1.1.3. Turkey Energy State

Turkey as part of the UN, is one of the high energy consumers which developed interval 70-163 million tonnes. Furthermore, Turkey contributes to countries that are dependent on fossil fuels to provide residential energy demands that result in a negative effect on both the environment and the economy. High-rise buildings have received a lot of attention in developing countries recently due to the high amount of energy consumption. Turkey has a great number of high-rise structures even though it is a developing country with a growing population and building restrictions. The energy consumption for residential and commercial buildings in Turkey is more remarkable rather than in other counties. Whereas the global range of high-rise building energy consumption is 16%-50%, with Turkey accounting for 31% [24], [25]. For this reason, it is essential to design energy-efficient high-rise buildings with a long-life cycle. Otherwise, the building's energy consumption and carbon emissions would be staggering.

Some studies address the impact of the building envelope on heating and cooling demand in high-rise buildings in Turkey. However, only few studies have concentrated on comparing wall structures of high-rise buildings. It is crystal clear that the gap in the architecture, engineering, and construction literature is the investigation of the effect of building envelope on heating and cooling demand in terms of building orientation, window-to-wall ratio, and wind direction. For instance, Dincer and Mahlayanlar (2020) performed an analysis of the air corridor façade in the highest building in Turkey to reduce its cooling and heating demand via DesignBuilder and EnergyPlus [26].

1.1.4. Building Envelope and Effective Factors

Studies show that demand for high-rise buildings has surged due to rapid urban population expansion[27]. As the thermal resistance of the facade decreases, the energy consumption of high-rise buildings increases as a result of their high transparency ratio [28]. High-rise buildings are more affected by environmental conditions due to their larger facade area. Therefore, the envelope of high-rise buildings contributes significantly to energy sharing [28]. For this reason, high-rise buildings have both advantages and disadvantages if they are not designed properly. The building envelope optimization have the potential to reduce the heating and cooling load to a minimum level[11], [12].

Improving building envelope performance and increasing cooling and heating equipment efficiency cover the highest amount of buildings-related emissions among the building-specific interventions [29].

The building envelope covers several components and materials that separate the conditioned indoor environment from the outside world. The foundation, walls, windows, doors, and roof are all part of the building envelope [30]. Consequently, heat transfer and thermal conductivity of building envelope components are essential elements in the reduction of heating and cooling demand, which will result in decreasing indirect carbon emissions in buildings [31], [32]. Following the scope of the Establishment of Energy Efficiency Building Codes (EEBCs), the envelope component is addressed in every country because it has a significant impact on the energy consumption levels of buildings [33].

Previous research has shown that one of the most important factors considered in building design is the local climate. Professionals designed vernacular architecture by considering the position of the sun and available resources (e.g., orientation, window-wall ratio, shading, natural vents, and form of the building). Passive measures such as building orientation/geometry, shade components, and wind barriers are used for achieving this goal. Implementing passive systems could save roughly 70% of the energy required for heating and cooling. Hence, a decrease in building energy consumption requires heating and cooling indoor spaces by a significant amount [34], [35]. Building envelopes could be optimized to maximize solar energy, lower greenhouse gas emissions, and reduce energy consumption.

Recently, considering climate change, heating demand has decreased, and cooling demand has increased as announced in the key World statistics in 2020. According to these statistics, heating energy demand per floor equates to 75 (KW/m2), and cooling energy demand equates to 41.66 (KW/m2) [4]. Besides, electricity demand for buildings increased by 3.8% between 1973 and 2018. According to the statistics, heating and cooling share 10% of buildings' final energy consumption [4]. Yildiz (2016) discovered that residential buildings have a significant effect on heating and cooling loads in Turkey [36]. Although the annual energy demand of new and existing residential buildings for heating is expected to decrease by 9-29% until the 2080s, cooling demand is expected to increase by 1.7-30%- through applying passive cooling strategies.

1.2. The Background of Energy Performance and Energy Efficiency in Literature

According to the literature review, the interest in building energy performance in the architecture, engineering and construction (AEC) industry has been increasing in the last decades. Substantially, out of 5028 publications, 144 are review articles that generally focus on energy efficiency, energy performance, heat, power control technologies, indoor environment quality, and retrofit practices [37]. In detail, 144 review articles address shallow geothermal resources [38], appraisal of PV system installation and the factors that impact their performance [39], thermal performance and envelope thermal design of building [40], urban building energy modelling tools [41], evaluating the impact of geometry, microclimate, and macroclimate on natural ventilation [42], smart building with the self-tuned indoor thermal environment [43], [44], human thermal physiology and thermal comfort/discomfort [45], using artificial neural networks meta-models for building performance simulation [46], influential factors on energy efficiency design of building[47], personal comfort system [48], machine learning in building life cycle assessment [28], renewable energy and electricity requirement forecasting model for smart grid and buildings [9], green building certification methods and metrics using to assess the quality of the indoor environment [9], and the impact of acoustic, thermal and illumination on occupants and energy performance [49].

1.2.1. Research Gap

Even though the literature on energy performance involves 144 review articles, mainly in the Architecture, Engineering, and Construction (AEC) industry scope, four studies conducted a bibliometric analysis while only one study [50] extensively analyzed the literature regarding energy efficiency. These studies focused on "energy efficiency" with the following sub-themes: energy performance, energy management, heat, power and control technologies, indoor environment quality, intelligent building, green building, low-carbon buildings, smart grid, and retrofit practice.

Santos et al. (2017) conducted a bibliometric analysis with existing literature on BIM within the last decade to identify collaborative environment and interoperability, sustainable construction, BIM adoption, standardization, and programming [50]. However, Santos et al (2017) did not map the scientific research of energy efficiency in the AEC industry to uncover the current status, hot topics and keywords, productive countries and institutions, research gaps, and emerging areas in this topic. A more recent study performed by Simpson et al. (2020) considered the data-centric method to improve indoor environment quality and materials impact [37]. The research of Simpson et al. (2020) used bibliometric analysis to identify research interests in dwelling retrofit studies across North-western Europe [37]. In this scope, Geraldi et al. (2020) conducted a meta-analysis review regarding energy performance for building-level analysis and stock-level analysis within the operational stage about empirical works that have been implicated in the whole building to examine energy use [51]. Bravo et al. (2020) addressed air conditioning and heating systems in their study to evaluate the design and operation of cooling and heating systems in green and smart buildings [44].

In addition to these studies, among 5028 records examined within the scope of this research, only three studies performed a brief scientometric analysis within the scope of their works. These papers focus on BIM for improving energy efficiency [52], bioclimatic architecture impacts on energy conservation [53], and urban building energy modeling (UBEM) [54]. Pereira et al. (2021) conducted a scientometric analysis on the integrated usage of BIM and energy efficiency [52]. However, the study of Pereira et al (2021) only focuses on a subtopic of energy efficiency research. Another study conducted by Aghimien et al. (2021) reviewed the existing studies on bioclimatic architecture to disclose previous achievements in enhancing building energy efficiency [53]. Nevertheless, Aghimien et al. (2021)'s study is limited to bioclimatic architecture and did not provide an inclusive understanding of the current status, hot keywords and topics, and emerging areas of energy performance in the AEC industry [53]. Ali et al. (2021) addressed urban building energy modeling (UBEM) and performed a brief scientometrics, literature review, and SWOT (strengths, weaknesses, opportunities, and threats) analysis for this topic [54]. However, the work of Ali et al (2021) is limited to UBEM studies. These three studies did not conduct holistic research on energy performance in the AEC industry. Accordingly, these studies have limited bibliometric records and metrics that may not provide a comprehensive understanding of the recent status, hot topics, and emerging areas of energy performance in the AEC industry [52]–[55].

Furthermore, among the works which were investigated in the scope of high rise building envelope energy efficiency, the main focused were on switchable glazing in high-rise residential building[14], the technical, economic, environmental, and comfort implications of new glazing technologies [5, 14], the impact of thermal bridge of balcony slab on envelope [16], the effects of shape coefficient on envelope load and energy consumption [17], floor-to-ceiling glazed areas impact on thermal resilience [18], assessing glazing type window-to-wall ratio, sun shading, and roof strategies for envelope design [18,19,20], climatically responsive design and microclimate interaction with envelope structure [22], infiltration and pressurizing in higher levels of building [23], investigating heat transfer through envelope components [19, 20], examining the efficiency of light-weight and low energy dynamic insulation, air-tight cavity function, and low-E coating [24], efficient energy codes and insulation materials [25], analyzing double skin brick wall façade and thermal transmittance (U-value) [26], the impact of location and surrounding [27], improving the envelope design parameters, optimizing plan layout, and taking advantage of natural ventilation to diminish heating and cooling energy demand and carbon emissions [27, 28].

Further, building early-stage design is one of the essential steps for all types of buildings to achieve high energy efficiency. Especially, it is necessary to consider the efficient system in designing residential buildings due to their large scale and high energy consumption. Additionally, high-rise building designs contain complexity and need precise design and sustainability goals to achieve high performance [56]. When building designers have options (i.e., design variables), they evaluate envelope components during the design stage. Their evaluation goes beyond the isolated performance of a single variable decision to examine the impact of one variable on another [57]. Walls, roofs, windows, doors, and foundations are part of the building envelope. Exterior cladding, exterior sheathing membrane, exterior sheathing, insulation, structural components, vapor barriers, and interior sheathings are components of a building's walls. Besides, wall assembly supports, controls, and finishes the building exterior [58].

Findings from the literature review demonstrate that none of the existing studies analyze energy performance research holistically, although plenty of studies on energy performance have been conducted in the last decade. Additionally, there is a lack of information about the influential factors in energy performance research and the interaction among the influential factors in achieving high energy performance in the AEC industry. For this reason, there is an obvious necessity for examining the existing body of knowledge on energy performance holistically to help researchers, policymakers, and stakeholders. Such study can make a valuable contribution to the AEC literature and industry by providing a comprehensive understanding of the current status, research patterns and priorities, hot keywords and topics, investing institutions and countries, implementation policies, and emerging areas of energy performance. Additionally, although several studies on energy-efficient buildings exist in the architecture, engineering, and construction (AEC) literature, none of them addresses the heating and cooling performance of high-rise building envelope materials. Such research would be a useful guideline for the early decision-making process in energy-efficient high-rise building design.

1.2.2. Research Objective

This study aims to (1) build up a knowledge base for exploring the optimal building envelope components based on the relevant aspects of energy performance to design energy-efficient high-rise buildings and (2) analyze and compare the effects of three different building envelope materials (i.e., reinforce concrete, timber wall, and curtain wall) on energy performance in a high-rise residential building.

Within the scope of this study, the following research questions were addressed:

- What is the relationship between the study's parameters of interest? How do they interact with one another (for example, wall structure, window-to-wall ratio (WWR), and orientation), and how do they influence building energy performance?
- Does the interaction of factors and the combination of parameters improve energy efficiency and reduce carbon emissions?
- Does the interaction of parameters and their combination affect energy efficiency and the reduction of carbon emissions?

The results revealed the best-fit components and variables for the aforementioned parameters to achieve high energy efficiency in a high-rise residential building. The findings of this study would lay the groundwork for improving the building envelope and façade in an energy-efficient manner. The results would shed light on the various aspects and components of the building envelope.

1.3. Thesis outline:

Chapter I provides introductory information about the building energy efficiency, research gaps, and research objectives. Chapter II explains the research methodology where the steps of the thesis were interpreted in detail, the software used in the study was introduced and the influential measurement was discussed. Chapter III presents the findings from the literature and science mapping. The literature review composes of two-part, first the literature in the scope of science mapping and energy performance in the AEC industry, second the literature within the scope of the energy performance of building envelope. In Chapter IV, the results gathered from heating and cooling analyses are discussed and interpreted. In Chapter V, the thesis conclusion is clarified comprehensively. Chapter VI addresses the thesis contribution and the research scope for future works. In Appendices, the graphs of analysis are provided in detail and the previous research related to this thesis is presented.

.

CHAPTER II

METHODOLOGY

2.1 The Steps of Research Methodology

Within this thesis, a mixed methodological approach was applied that includes systematic literature review, scientometric literature review, and case study analyses. The first step is a systematic literature review, and the explored bibliometric data were imported to science mapping software for scientometric analyses. Then, the findings of scientometric analyses were evaluated and assisted in the thesis hypothesis to define the case study and perform investigations. In the case study, Design Builder was utilized for modeling and evaluating the envelope components' impact on energy consumption for heating and cooling demand.

2.1.1. Scientometric analysis

The objective of performing a scientometric analysis is to map the knowledge field explicitly. Indeed, the scientometric analysis includes both qualitative and quantitative analysis while using various tools like citing mapping, visualization, co-authorship network, and co-word mapping. Scientometrics allows researchers to visualize the patterns and trends hidden in many pieces of literature and bibliographic records by evaluating the research development and performance of researchers, countries, institutions, journals, and documents in a specific field via different networks [59].

There are various science mapping tools to visualize and evaluate trends and patterns in scientific records. Science mapping tools are classified as specific (e.g., CoPalTed, Science of Science Tool, or VOSviewer) and nonspecific (e.g., Pajek, Gephi, or UCIENT)[60]. Each tool has powerful aspects and abilities according to the type of analysis required. According to the previous studies, none of the software can incorporate primary retrieval data elements, pre-processing, mapping, visualization, description, normalization, and network extraction [60]. Hence, previous studies suggested using more than one science mapping tool [60]. Therefore, Cite Space, VOSviewer, and Gephi opted for this study to ensure highly reliable outputs.

CiteSpace is responsible for establishing the networks with nodes and dynamic graphs to bursting and cluster analysis of the networks. According to the essential requirements of scientometric analysis, citation analysis has a fundamental factor[61]. WoS provides high satisfaction for users to implement citation analysis, which is essential for scientometric analysis. Due to the in-depth citation search and mapping research fields, the CiteSpace program evaluates citation search and relevant details. Hereafter, the networks were imported to VOSviewer and Gephi, whereby higher quality visuals can be achieved.

2.1.2. Scientometric Techniques

Scientometric analysis can be classified into three techniques which are 'one dimensional' (based on occurrence/happening, directly focuses on count/number like citation, keyword, and publication), 'two dimensional' (focuses on the co-occurrence of classification codes, and the number of times of keyword), and 'multi-dimensional' (classifying as continuous and discontinuous). The continuous method in the multi-dimensional scientometric analysis displays structural features of data in the form of maps, whereas the discontinuous technique assists in scaling down when the intensity of observation is concerned[62].

In this research co-word, cluster, co-author, and co-citation analyses were conducted. Co-word analysis consists of keyword co-occurrence, keyword citation burst, and keyword cluster analyses. On the other hand, the co-author's analysis consists of a network of countries/regions, the network of institutions, most productive organization. Hereafter, the co-citation analysis consists of the author co-citation network, the journal co-citation network, and a document co-citation network. Additionally, the cluster of document co-citation analysis was established to evaluate the clusters, and keyword co-occurrence analysis reveals the concurrency of keywords simultaneously. This analysis develops links between the keywords that have coincided in the literature. Moreover, it aids in discovering the pattern and structure of knowledge in the research process. Co-citation networks assist in determining the citing behavior.

Consequently, keyword citation burst analysis displays terms that have drawn much attention through research publications/citations over a while [63]. Detecting the burst in a network illustrates the rising interest. Citespace 0.2.9 software was used to perform the burst analysis. Finally, the pattern and structure of knowledge could be studied for classification and made more comprehensible by analyzing the nodes, particularly the keywords. This process is known as cluster analysis [64].

2.1.2.1. Metrics and Properties in Scientometric Analysis

There are various properties and metrics involved when conducting a scientometric analysis. These metrics and properties used in the analysis and investigation throughout this study are degree centrality, betweenness centrality, modularity, and mean silhouette.

2.1.2.2. Degree Centrality

The degree centrality value demonstrates the number of links/connections between nodes of a network. This variable is an essential measure of a node that composes links with other nodes. The degree of centrality assists in determining the connections, communities, and the popular node and reveals the nodes that are likely to contain the most data or nodes that can be swiftly linked to the rest of the network[65]. Therefore, the degree of centrality was used in this study to discover the most influential keyword, country, institution, document, journal, author, and their relation/connection along with their degree of contribution to the literature on energy performance[66].

2.1.2.3. Betweenness Centrality

Betweenness centrality identifies which node acts as a ‘bridge’ to connect the nodes and establish communities. A high betweenness count for a node implies that it has power over, or influences collaboration between, many clusters in a network or that it is on the outskirts of two clusters[65]. The data were first analyzed with the VOSviewer 1.6.16 to create a network of terms to compute betweenness centrality values for keywords. The network was then uploaded into Gephi 0.9.2 software, which was used to calculate the betweenness centrality values. Betweenness centrality values were utilized in conjunction with degree centrality values to determine the terms with higher authority in the energy performance literature[66].

2.1.2.4. Modularity and Mean Silhouette

Modularity indicates the communities in the network and aids in classifying the network into separated clusters. Modularity can be computed via VOSviewer. This study adjusted the node’s rank to the modularity class to visualize the results. Therefore, witnessing a high percentage of a cluster indicates the high contributions of that cluster within the analyzed network. Moreover, modularity analysis provides a situation to understand the flow of the information and existing connected or disconnected nodes within the network. It is possible to eliminate the disconnected nodes and filter them to clarify mapping and more understandable visualization.

The Silhouette score (S) is a metric for how closely an object resembles its cluster (cohesion) in comparison to other clusters (separation). It has a range of -1 to 1. A high silhouette score suggests that an item is well matched to its cluster or group but poorly matched to neighboring clusters, which is helpful for clustering [64]. For instance, keywords like buildings, energy systems, calibrating models, adjoint-based sensitivity method, Brazilian public schools, influencing variables, thermal performance, indoor air quality, and automated optimal motion sequence seem to be classified under one cluster as they all are related keywords and associated with sensitivity analyses. Thus, the cluster's silhouette score S will be high in such situations. The silhouette score S will be low if the unrelated terms [67].

2.2. Systematic Literature Review

The findings of scientometric analyses aid in defining the case study’s hypothesis and the thesis keywords. In the review, “energy performance”, “energy use”, and “energy efficiency” were searched in the scope of “architecture”, “construction building technology”, and “civil engineering” using Web of Science and Scopus for the 2010-2022 timespan. Hence, the literature was reviewed and limited by 2 groups of keywords ‘energy performance’, ‘energy efficiency’, ‘building envelope impact ’, ‘ cooling ’, and ‘ high-rise ’ and second for the following keywords; ‘ energy performance ’, ‘ energy efficiency ’, ‘ building envelope ’, ‘ material ’, ‘ energy analysis ’, and ‘ Design Builder’.

Since this research intends to cover all the relevant publications addressing this topic to conduct an inclusive mapping of the scientific research, all the publication types (i.e., journal articles, conference proceedings, and book chapters) were included within the scope of this review.

For the first group, studies that were published between 2011 and 2021 were analyzed within the scope of the first group of keywords. Thirty publications were identified based on their time frame (2011-2021) and categories (i.e., civil engineering, architecture, and building construction technology). After selecting the publications manually, 23 articles were determined in the field of building envelope's impact on cooling demand within the categories of civil engineering, architecture, building, and construction technologies. It is worth noting that the first article on the impact of building envelopes on cooling demand was published in 2006. A review of the literature demonstrates that there are very limited studies on high-rise buildings and their envelopes.

Afterward, the keywords used in the search engine were as follows; 'energy performance', 'energy efficiency', 'building envelope', 'material', 'energy analysis', and ' Design Builder '. 648 publications were limited by duration (2015-2021) and refined categories concerning 'civil engineering', 'architecture', and 'building construction technology'. Then, 84 publications were extracted. However, there is a lack of research about high-rise buildings and building envelopes. There are 118 publications on the scope of the energy performance of high-rise residential buildings (under categories of civil engineering, architecture, building, and construction technologies). The first article on this topic was published in 2000. The publication has been forwarded by 17, 18, 11, and 10 in the years 2021,2020, 2019, and 2018, respectively. These parts of knowledge body prove that insufficient consideration of high residential building energy performance exist in the literature. Indeed, only seven articles addressing building energy performance on high-rise buildings have been published in the last 5 years.

2.3. Design Builder:

Design builder is an interface software that uses Energy Plus to simulate building energy performance. This software is user-friendly software that provides modeling and energy analysis so fast and easy. Design Builder 7.0.0.116 was selected for modeling the case study building as this software provides modeling and various energy analyses which are performed by Energy Plus, the graphical interface of Design Builder.

2.4. Case study:

In the third step of this research, Design Builder was used for designing a 10-story reinforced concrete high-rise residential building model according to ASHRAE 90.1-2016 standard. In Figure 3, the model of the case study building and the sun path for July, as the warmest summer month. The total area of the case study building is 5400 m^2, with 540 m^2 of floor space. The width of the case study building is 27m and its height is 20m. The building measures (width and height) and form were assumed the same for all the scenarios. The stand-alone model for the case study building designed via Design Builder is presented in Figures 3 and 4. Besides, the structure of the wall components (including an external wall, a below-grade wall, a semi-exposed wall, and a sub-surface wall) used in the design of the case study building is shown in Figure 5.

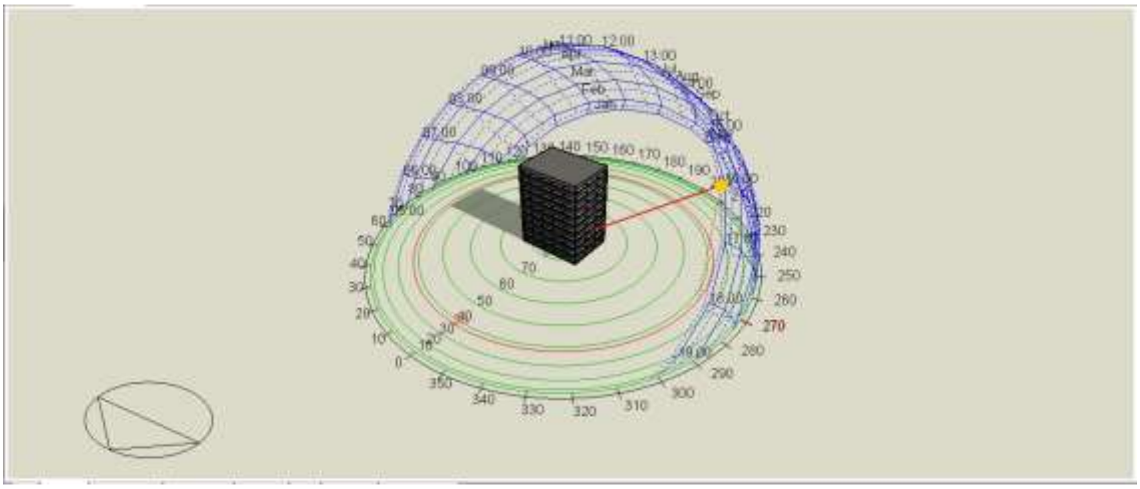


Figure 3. The model of the case study building and sun path

Figure 4. The stand-alone model for case study building in DesignBuilder

The structure of the Wall components is illustrated in Figure 5. The inner surface, outer surface, and middle layer are assumed as identified in the project, curtain wall, and timber wall template in the Design-Builder. Within this study, the scope of focus is on the envelope of the building, therefore the internal plan is not considered.

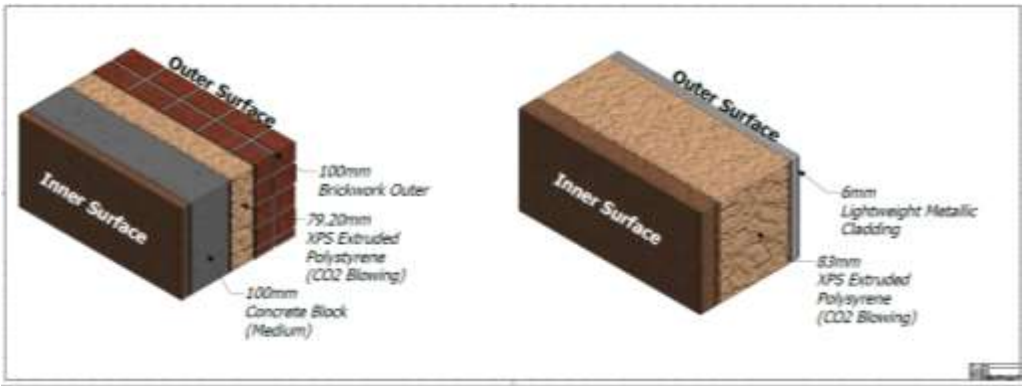


Figure 5. Structure of wall components (left picture. curtain wall, the right picture demonstrates timber frame wall super insulated)

2.5. Climate Zone:

The case study building locates in Istanbul, Turkey at the latitude and longitude coordinates of 41.015137° North, 28.979530° East, and 37 meters above the sea. The data library and the wall elements were selected based on the most used components in Istanbul. According to the Koppen classification (Cfa), Istanbul is classified under a subtropical humid climate. Considering the climate in Istanbul, winter begins in October and ends in March, while summer begins in April and finishes in September in this scenario. Throughout the year, the temperature fluctuates between 0 and 30 degrees. During the study, the course of the sun is considered for various months of the year, as illustrated in Figure 3**.** Moreover, the wind directions that Istanbul is exposed to them (Figure 6) have different impacts as mentioned in Table 1.

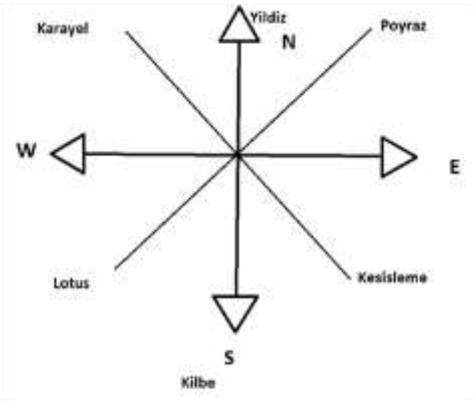


Figure 6. The wind direction in Istanbul

Table 1. Direction and impact of winds in Istanbul

Wind name	Direction	Warm/cold	Summer	Winter
Star (Yıldız)	North	Cold	Cool	Cold
North wind (Poyraz)	North East	Cold	Cool	Cold
Southeastward (Keşişleme)	South East	Warm	Provide dryness	Decrease humidity
Kilba (Kilbe)	South	Warm	Reason for dry bulb	Reason for dry coldness
South (Lodos)	South West	Warm	Brings rain clouds	Turns North and cold
Mistral (Karayel)	North West	Cold	Provide natural cooling	Cold

Source: These data were obtained from [68](https://www.havaforum.com/)

2.6. Simulation criteria for cooling analysis:

After the stand-alone model for the case study building was created, the activity setup was adjusted (Table 2) and all the assumptions were developed based on ASHRAE 90.1 -2016. Additionally, the reference building design criteria are given in Table 3. The uninsulated, typical reference, obligatory energy code, and ASHRAE 90.1-2016 were used for performing the cooling analysis. In the case study, a cold winter 'best practice' was chosen as the best practice energy code. In addition, the setup for lighting, HVAC, and occupancy were adjusted concerning ASHRAE 90.1-2016 as summarized in Table 2.

Table 2. Setup details for the activity tab to implement simulation

Activity template	Template	Residential –dwelling unit(with kitchen)
	Include zone in the thermal calculation	Yes
	Include zone in radiance daylighting calculation	Yes
ASHRAE 90.1 setting	ASHRAE 90.1 building type	Proposed
	Primary building condition category	Residential
	Heating source	Fossil fuel or fossil fuel /hybrid or purchased heat
	ASHRAE 90.1 lighting category	2016 space category(Dining Area-Family dining)
	ASHRAE 90.1 floor definition	User-defined
	ASHRAE 90.1 building area type	Other
Occupancy	Occupied	Yes
	Occupancy density (people/m^2)	0.0215
	Schedule	Residential occupancy
Metabolic	Activity	Cooking
	Factor (Men-1.00, Women=0.85,children=0.75)	1.00
	CO^2 generation rate(m^3/s-w)	0.0000000382

	Clothing schedule definition	Generic summer and winter clothing
	Winter clothing (clo)	1.00
	Summer clothing(clo)	0.50
	Comfort radiant temperature	Zone averaged
	Air velocity	Default air velocity comfort calculation
Holidays	Holidays per year	5 days
	Holidays Schedule	General holidays
Environmental control	Heating setpoint temperature	
	Heating (°C)	24.0
	Heating setback (°C)	18.0
	Cooling setpoint temperatures	
	Cooling (°C)	18.00
	Cooling setback (°C)	26.00
Humidity control	RH humidification setpoint(%)	10.0
	RH dehumidification setpoint(%)	90.0
Ventilation setpoint	Indoor min temperature control	Yes
	Min temperature definition	By schedule
	Min temperature schedule	Min indoor temperature for natural vent: always 7/24
	Indoor max temperature control	Yes
	Minimum fresh air (I/S-person)	2.360
	Mech vent per area(I/S-m^2)	0.305
Lighting	Target illuminance(Lux)	100
	Default display lighting density (W/m2)	2,9063 W/m^2
	Catering	Yes

Table 3. Reference building design criteria for the cooling analysis

Floor, roof, and wall U-Values (W/m^2-K)	External Floor	0.35
	Ground Floor	0.25
	Internal Floor	1.50
	Internal partitions wall	1.00
	Roof	2.00
	Wall - Typical reference – Lightweight	0,347
Glazing	WWR	40%
	Glazing Type	reference glazing (2 layers, air)
	U-Value(W/m^2K)	1.978
	Total solar transmission (SHGC)	0.691
	Shading	No Shading Devices
Lighting	Template	Building Area Method, Multifamily – ASHRAE 90.1
	Power Density	2,9063W/m^2 at 100 lux
HVAC	Ventilation	Natural (no vents)
	Template	FCU 4-pipe, Air-cooled chiller
	Boiler Efficiency	0.85
	Chiller CoP	1.80
Occupancy	Heating Setpoint	18°C based on ASHRAE 90.1
	Cooling Setpoint	26°C based on ASHRAE 90.1
WWR	40% vertical glazing ASHRAE 90.1	40%
Site Orientation		0°C

Chapter III

LITERATURE REVIEW

3.1 Research Background on Energy Performance

In the review, a total of 5028 publications were extracted from the WoS database in February 2022. Among these publications, 4975 are in English, 25 are in Spanish, 21 are in German, 4 in Italian,2 in Turkish,1 in Croatian,1 in Estonian, and 1 in Russian. Figure 7 demonstrates the frequency and cumulative distribution of 5028 publications within the timeframe. In Figure 7, the horizontal axis demonstrates the year of publication while the vertical axis demonstrates the number of publications per year and cumulative frequency accordingly. The total number of publications per year is shown by green vertical bars. Each year's percentage frequency was calculated (articles per year divided by the total number of publications in 2010-2022 multiplied by 100), demonstrating the amount of activity per year in the literature on energy performance interval 2010-2022 which is presented by the yellow line. Cumulative frequency shown in the blue increasing line along the vertical green bars was also calculated, showing the number of publications within the considered period (between 2010-2022). The dashed line in Figure 7 presents ascending/descending course according to the cumulative frequency in the growth path. According to Figure 7, the most productive year was 2021, with 689 publications. The lowest output per year belongs in 2010. The leading cause of the lowest number of publications in 2010 might be the novelty of energy performance gaining attention in various aspects. The second-lowest number of publications belongs to 2022 because this research was performed on the 15th of February. The growth path is ascending except for 2019 and 2022.

The associated publications within the scope of building energy performance in the AEC literature were included, while the works which are not directly related to the scope of this research were excluded. Upon the search on Web of Science, 3117 extracted records were in the scope of "buildings". Out of 2940 publications, 364 records are related to "renewable energy", 354 records are linked to "sustainability", 322 records focus on "green building", 595 records are associated with "solar energy", 613 records address "thermal comfort", and 293 records are related to "innovation". These records were extensively reviewed to accomplish complete mapping, and the citation search was expanded. Consequently, the commencement of development mentioned before scopes was in 2016 mostly.

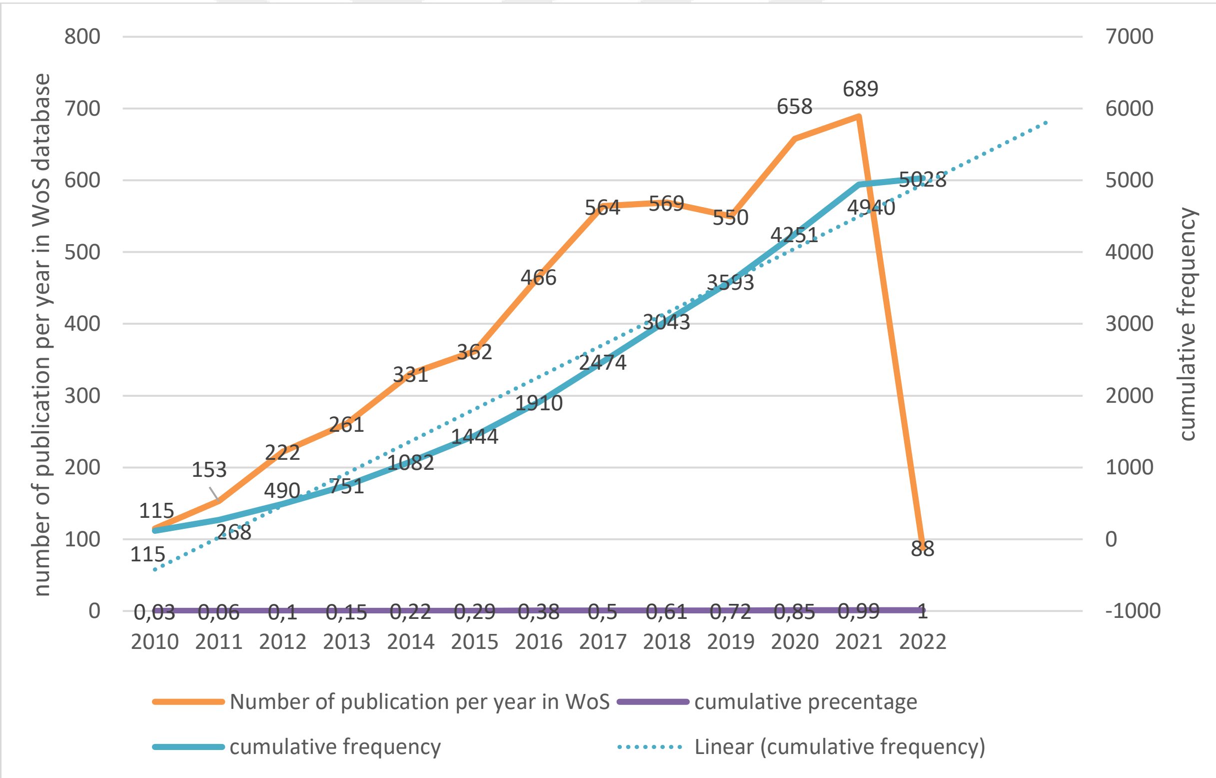


Figure 7. Number of publications on the building energy performance between 2010-2022 in the WoS database

Previous studies on energy performance and energy efficiency focused on the applications of machine learning in the life cycle of buildings [69], sensitivity analysis for building energy performance [66], [70], energy performance of the building during operational stage [51], [71], assessing indoor environment and thermal comfort in case of their impact on energy performance of dwelling in residential building stock [72], [73], Net Zero Energy Building (NZEBs) to provide thermal comfort and energy performance [74], [75], effect of thermal insulation, shading devices, window to wall ration and combination of them on energy use [76], [77], genetic algorithm for multi-objective optimization of building retrofitting [78], assessing human dimension of energy consumption in building life span [71], [79], [80], perovskite solar cells for building-integrated photovoltaics (BIPV)[81], data-centric innovation in retrofitting of dwelling[37], photovoltaics in built environments[82], energy efficiency and carbon emission in high rise building[83], bioclimatic design elements[84], BIM for improvement of building energy efficiency[52], and applications of augmented reality in civil infrastructure[85]. In addition, machine learning and advanced algorithms are applied to compute big data as a solution to enhance energy performance [86]. Concerning that, Hong et al. (2020) [86] performed a survey on how machine learning is implemented in different stages of the building lifecycle. “Energy performance” is the main keyword for applying in-depth research through scientometrics.

3.2. Keyword Co-occurrence

Keyword co-occurrence analysis intends to show the expertise structure / rational structure of studies on energy performance in the AEC industry. The keyword network confirmed the relationship between existing interest in the literature and its arrangement. For this purpose, VOSviewer was used for generating the primary pursuits of studies addressing energy performance in the AEC industry. A co-occurrence network encompasses numerous objects or considers one among them (e.g., keyword, institution, countries, and journals) with the due intention for evaluation. In a co-occurrence network, the nodes constitute the items while the links/edges represent the connections among objects. Therefore, in the keyword co-occurrence network, the nodes constitute keywords, and the links represent connections/relations among keywords. Since the co-occurrence networks are commonly weighted, simultaneously, they can indicate the weak spot or strength of the relation of most of the keywords.

Along with implementing analysis, there are two options to generate a keyword co-occurrence network: ‘all keywords’ (based on the keywords defined by author/authors and the keywords defined by Web of Science) and ‘author keyword’. ‘All keywords’ is selected to implement for the analysis in this study. 'All keyword’ is as beneficial as the ‘author keyword’ in the bibliometric analysis to figure out the expertise area in the studies. As a result, choosing 'all keyword' to conduct analysis provides a comprehensive and more elaborate study than choosing 'author keyword’ while providing a thorough review of utilized terms. As a fractional counting adjustment, ‘full counting' was chosen in the next phase. Fractional counting is responsible for assigning weight to described items (i.e., keyword, institution, journal, and countries) in the co-citation or co-author networks fractionally. Consequently, fractional counting of resources decreases the impact of co-authored publications in co-authorship analysis [87].

In this regard, 13.208 keywords were acquired from the bibliometric database by performing fractional counting within keyword co-occurrence analysis. The minimal range of occurrence was adjusted to over 30 for investigating keywords with high co-occurrence. With this inclusion, 108 out of 13.208 keywords were detected following a minimum occurrence of 30 and 5 clusters composed of 3529 links [69]. Figure 8 demonstrates the keyword co-occurrence network.

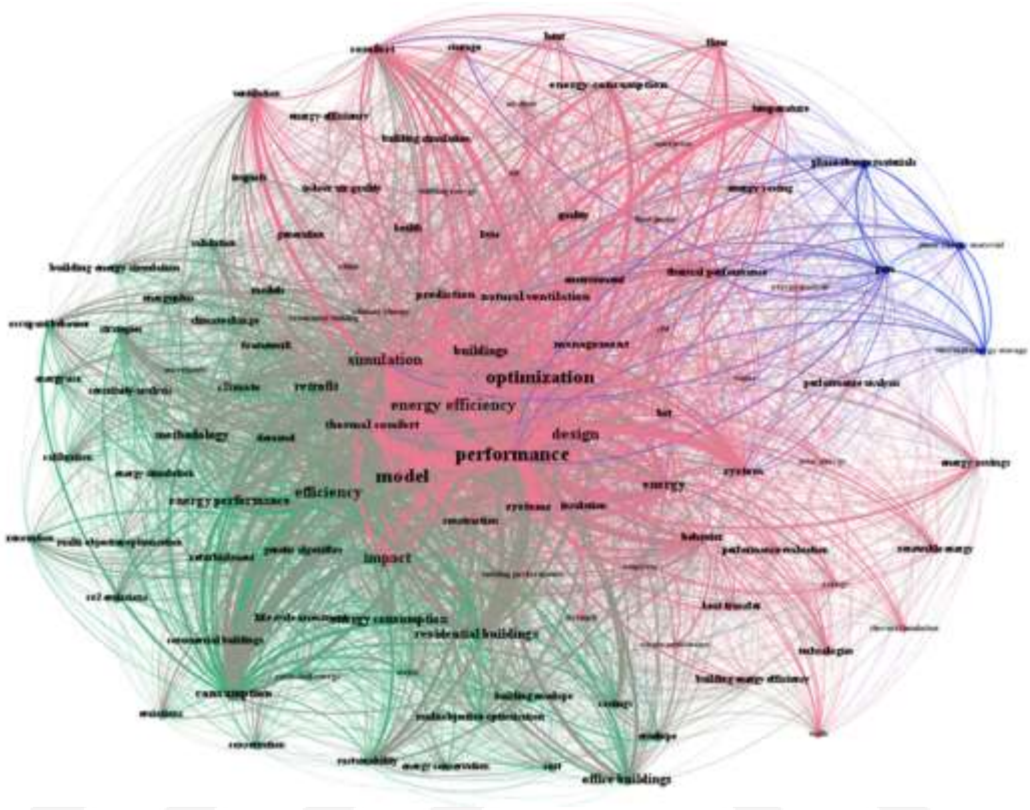


Figure 8. Network of keywords co-occurrence analysis

Afterward, the network generated via VOSviewer 1.6.16 was imported to Gephi 0.9.2 to conduct different evaluations and acquire critical metrics. This research estimated and evaluated degree centrality/link and betweenness centrality via Gephi 0.9.2 software, including 91 more keywords associated with energy performance. Some exact keywords are ‘energy’, ‘energy efficiency’, ‘ energy use ’, and ‘ consumption ’.

Degree centrality constitutes the most influential node as it demonstrates the number of connections among the latter. Since this metric is one of the dependable and precise metrics to ascertain the most influential node[87], a node's high degree centrality value means how effective the node is. The betweenness centrality is a measure to define how nodes participate in the network as a ‘bridge’ among other nodes. Their centrality degree and their betweenness centrality are classified with the same centrality degree to assess the keywords.

As shown in Figure 8 and Table 4**,** some nodes and keywords have a high degree of centrality and betweenness centrality simultaneously. ‘Efficiency’ and ‘design’ have the highest centrality degree, and these two keywords are the seventh node with the highest betweenness centrality. It means both ‘efficiency’ and ‘design’ are influential keywords in the network since they participate powerfully as a bridge in the network. ‘Performance’ has the highest betweenness centrality, and it is the second node with the highest degree of centrality. Because ‘performance' is a crucial function in the building and construction sector, it has the highest betweenness centrality and centrality degree by demonstrating this keyword's relevance and influence in the network. ‘Simulation’ is the fourth node with the highest centrality degree and the third node with the highest betweenness centrality. According to the outputs, ‘efficiency’, ‘performance’, and ‘energy efficiency are the most influential keywords in the AEC literature with 107, 106, and 105 centralities degrees, respectively.

'Efficiency’ impacts on the following keywords: performance, buildings, simulation, residential building, consumption, demand, energy simulation, validation, comfort, thermal comfort, prediction, ventilation, environment, flow, temperature, system, technologies, renewable energy, impact, methodology, CO2 emission, renovation, framework, models, heat pump, phase change material, behavior, concrete, sustainability, retrofit, refurbishment, impact, exergy, and operation. ‘Performance’ impacts on the following keywords: efficiency, simulation, buildings, consumption, residential buildings, thermal comfort, ventilation, life cycle assessment, concrete, occupant behavior, CO_2 emission, sensitivity analysis, energy simulation, models, systems, office buildings, renewable energy, construction, walls, heat, water, strength, solar energy, phase change material, heat transfer, environment, airflow, CFD, climate change, management, technologies, insulation, performance analysis, sustainability, retrofit, refurbishment, energy plus, and validation. These links demonstrate that the keywords cover all the associated keywords due to the high similarity value. For this reason, 'energy efficiency ' is as influential as ' efficiency ' and ' performance ' because the keyword ' energy efficiency ' covers all the related keywords firmly like 'performance.'

Table 4. Keywords influence energy performance in AEC

Label	Centrality degree	Betweenness centrality
1. Efficiency	107	0.005647
2. Design	107	0.005647
3. Performance	106	0.00935
4. Simulation	106	0.006477
5. Energy efficiency	105	0.006397
6. Model	105	0.008812
7. Buildings	104	0.003239
8. Optimization	104	0.009129
9. Systems	100	0.002323
10. Thermal comfort	99	0.001445
11. Consumption	97	0.003976
12. Residential buildings	97	0.003706
13. energy performance	96	0.004477
14. impact	95	0.006332
15. system	93	0.002535
16. Thermal performance	90	0.001084

17. Behavior	86	0.00081
18. Comfort	86	0.002435
19. Temperature	85	0.001632
20. Office buildings	84	0.003653
21. Ventilation	83	0.000495
22. Energy consumption	83	0.003004
23. Retrofit	82	0.00423
24. Climate	81	0.002777
25. Building envelope	77	0.000891
26. Methodology	76	0.003301
27. Prediction	75	0.002187
28. Strategies	75	0.000605
29. Sustainability	73	0.000977
30. Demand	72	0.001345
31. Storage	72	0.00134
32. Natural ventilation	71	0.002464
33. Energy saving	70	0.001661
34. Environment	69	0.00222
35. Multi-objective optimization	68	0.002027
36. Construction	68	0.001083
37. Management	67	0.002497
38. Building energy simulation	67	0.001402
39. Energy-plus	66	0.002269
40. Sensitivity-analysis	65	0.000803
41. Occupant behavior	63	0.001067
42. Insulation	62	0.001224
43.Co2 emissions	62	0.001216
44. Energy use	62	0.001275
45. Renovation	60	0.000534
46. Heat	60	0.001803

47. Climate-change	60	0.000691
48. Technologies	59	0.000568
49. Cost	58	0.000708
50. Building simulation	58	0.000638
51. Impacts	58	0.001385
52. Building energy efficiency	58	0.000629
53.Pcmcm	57	0.001269
54. flow	57	0.001549
55.life-cycle assessment	57	0.001604
56. Envelope	57	0.001234
57. energy simulation	57	0.000998
58. energy conservation	57	0.001036
59. Quality	56	0.000686
60. renewable energy	56	0.000897
61. Calibration	56	0.000707
62. indoor air quality	55	0.000926
63. commercial buildings	55	0.000929
64. Walls	55	0.000273
65. Hvac	55	0.001378
66. Health	54	0.000938
67. Building Performance	54	0.000358
68. Phase-change materials	53	0.001611
69. Refurbishment	53	0.001165
70. Conservation	53	0.00067
71. Emissions	52	0.001173
72. Framework	51	0.000791
73. Sector	51	0.000411
74. genetic algorithm	50	0.001136
75. Concrete	50	0.000532
76.heat-transfer	50	0.001022

77. Water	50	0
78. performance analysis	50	0.001615
79. embodied energy	49	0.000622
80. Generation	49	0.001108
81. Performance evaluation	49	0.001114

Source: The results are calculated via Gephi 0.9.2

Regarding the analysis conducted via VOSviewer, ‘performance’ contributes to occurrences with a value of 1025, 943 total link strengths of 943, and 106 links. ‘Energy efficiency’ contributes to occurrence with 717, total link strength of 618, and 105 links. ‘Efficiency’ contributes to occurrences with 419, 393 total link strength and 107 links. Meanwhile, ‘design’, ‘simulation’, ‘building’, ‘optimization’, ‘consumption’, ‘model’, ‘energy’, and ‘thermal comfort’ are the ten keywords with the highest occurrence which took account in the network of keyword co-occurrence with 387, 366, 356, 306, 261, 261, 266, and 242 occurrences, respectively.

Based on these data, 'performance' occurs more often, and 'effectiveness' is thus the most centralized. These keywords are essential and influential within the AEC literature, upon having energy performance/energy efficiency as one of the leading research objectives. Hence, the strong links among the keywords indicate the requirement to assess the factors that affect AEC's performance and efficiencies, such as climate, energy simulation, optimization, design, energy consumption, model, and thermal performance. This result indicates that the keywords (i.e., efficiency, performance, and energy efficiency) are dependent on each other. In addition, these keywords are associated with the other nodes (i.e., keywords), as each node takes apart an influential factor in achieving energy efficiency and high performance within construction projects and different types of buildings. Moreover, it is crystal clear that the strong existing links are between relative factors, which are subcategories of efficiency /performance.

'Optimization', 'performance', 'model', 'simulation', and 'energy efficiency' have the highest number of betweenness centrality, respectively. It emphasizes the essential role of these keywords as bridge keywords among other keywords and indicates their frequent usage in the network. The vital link and communication among keywords offer a solid foundation for research and literary creation. 'Simulation', 'modeling', 'energy efficiency', and 'performances' are remarkable factors/keywords in this field of study.

Keyword co-occurrence network is beneficial for discovering the fields neglected and disregarded in the literature. According to Figure 8, performance analysis, genetic algorithm, heat transfer, concrete, water, embodied energy, residential building, multi-objective optimization, climate change, computational fluid dynamic (CFD) modelling, airflow, heat pump, thermal insulation, phase change material, exergy analysis, and the seismic performance is considered within the keyword co-occurrence network with centrality degree interval (50-15) respectively. However, their betweenness centrality number is in the interval (0.000093 – 0.0016), which means these keywords were not actively considered in the previous studies and research areas in the interval 2010-2022. Each of them is an essential factor that can increase energy efficiency and energy performance. Thus, future works could focus on those keywords while investigating similar topics in the AEC industry.

3.3. Keyword Burst

The keyword co-occurrence burst analysis illustrates the rise in interest within the research process. Citespace0.2.9 was used for conducting the latter. The functionality of

Citespace for implementing burst analysis is based on Kleinberg's algorithm [88], which is the foundation of burst analysis [64], [89]. A keyword citation burst was performed based on a restricted outline of keyword co-occurrence analysis.

The citation improvement of keywords over several years or in a single year is demonstrated by citation burst analysis. Consequently, keyword burst analysis reveals citation frequency within the literature through a defined period of years. According to He et al. (2017), keyword burst analysis could be helpful to demonstrate the development and interest in research trends within a specific timeline [90]. The keyword burst analysis reveals the progression of energy performance literature and the changes of focus within the knowledge structure of energy performance during the interval 2010-2022. Meanwhile, this analysis assists in discovering the gaps and overlooked research in the literature within a specific timeline. According to Pollack and Adler's (2015) study, burst analysis can detect the changes and development of a body of knowledge within a period [91].

Hence, Citespace was used for conducting keyword burst analysis. Table 5 indicates 42 keywords that have an increased interest in energy performance literature within the last 11 years (2010-2022). In Table 5, the red bar/line indicates the citation burst of the keyword, and the blue bar/line indicates the literature review period of the last decade. The table is arranged year wisely.

Top 15 keywords with strongest citation burst are as follow, 'Energy, strength=7.14, from 2010 to 2014', 'Exergy, strength= 6.74, from 2011 to 2013', 'Removal, strength= 6.'36, from 2018 to 2019', 'Air, strength= 5.82, from 2011 to 2012', 'Performance gap, strength= 5.76, from 2017 to 2018', 'Sustainability, strength= 5.58, from 2010 to 2013', 'Green Building, strength= 5.2, from 2010 to 2015', 'Modeling, strength=5.2, from 2013 to 2016', 'Policy, strength=5.18 from 2018 to 2019', 'Ventilation, strength=4.89, from 2011 to 2012', 'School , strength= 4.86, from 2014 to 2016', 'Solar, strength=4.68, from 2014 to 2016', 'Net Zero Energy building , strength=4.45, from 2017 to 2018', and 'Technology, strength= 4.42, from 2018 to 2019'.

Moreover, recently noticed research topics based on their citation burst (i.e., the citation that span to 2015) are ' policy ', ' residential sector ', ' performance gap ', ' NZEB ', ' school building ', ' technology ', ' quality ', ' building design ', ' thermal comfort ', 'modeling', ' predictive control ', ' particulate matter ', ' implementation ', ' information ', ' heat storage ', ' CFD simulation ', ' roof ', ' wave energy ', ' reinforced concrete ', ' occupant behavior ', ' refurbishment ', ' building performance simulation ', ' household ', ' resistance ', ' field test ', and ' demand control ventilation '.

According to the results, a remarkable audience desires to research topics such as policy and regulations, energy performance, occupant comfort, green building, sustainability, modeling and simulation, monitoring and mobility, renewable energy, material impact, energy conservation, and reduce energy demand. Additionally, it is proven that these topics could enhance energy efficiency undertakings, sustainability, and the built environment in the literature because of their citation burst. Besides, these research topics aid in decision-making and various stages of construction to achieve developed energy performance through implementing policies. Nevertheless, some keywords citation burst is low (i.e., <3) such as (ranked in descending order) 'air conditioning ', ' energy conservation ', ' absorber ', ' heat exchanger ', and ' LEED. ' It is worth noting that the keywords with low citation burst are sub-themes of essential factors and requirements to achieve high performance and efficiency in the AEC industry.

Table 5. Top 42 keywords with the most robust citation bursts

Keywords	Year	Strength	Begin	End	2010 – 2021
energy	2010	7.14	2010	2014	
Sustainability	2010	5.58	2010	2013	
green building	2010	5.2	2010	2015	
Conservation	2010	4.24	2010	2012	
heat transfer	2010	4.22	2010	2015	
exergy analysis	2010	4.16	2010	2012	
Heat	2010	3.64	2010	2011	
Radiation	2010	3.62	2010	2014	
Housing	2010	3.55	2010	2015	
sustainable building	2010	3.55	2010	2016	
mass transfer	2010	3.37	2010	2011	
Collector	2010	3.15	2010	2013	
indoor air quality	2010	3.13	2010	2011	
Standard	2010	2.9	2010	2016	
energy conservation	2010	2.85	2010	2012	
Exergy	2010	6.74	2011	2013	
Air	2010	5.82	2011	2012	
Ventilation	2010	4.89	2011	2012	
Daylighting	2010	4.16	2011	2015	

district heating	2010	3.82	2011	2012
Residential	2010	3.42	2011	2016
Greenhouse	2010	3.27	2011	2013
Regulation	2010	2.97	2011	2013
air conditioning	2010	2.87	2011	2013
LEED	2010	2.69	2011	2014
building simulation	2010	3.47	2012	2013
Balance	2010	3.39	2012	2014
energy balance	2010	3.39	2012	2014
solar collector	2010	3.32	2012	2016
Measurement	2010	3.1	2012	2013
Wall	2010	3.07	2012	2014
Modeling	2010	5.2	2013	2016
energy efficiency	2010	4.31	2013	2014
double skin façade	2010	4.16	2013	2015
case study	2010	3.46	2013	2015
School	2010	4.86	2014	2016
Solar	2010	4.68	2014	2016
building energy	2010	3.8	2014	2016
dynamic simulation	2010	3.7	2014	2017
energy analysis	2010	3.41	2014	2017
energy management	2010	3.09	2014	2016

design optimization	2010	3.09	2014	2016
building stock	2010	2.94	2014	2015

Source: The results are obtained through Cistspace 5.7. R2

3.4. *Keyword Co-Occurrence Cluster Analysis*

Keywords related to energy performance were sorted into organized and manageable terms using cluster analysis. Cluster analysis is a technique that calculates the large body of knowledge into smaller and more digestible chunks. Cluster analysis is implemented through algorithms in grouping the body of knowledge (i.e., keywords) that are unstructured[90]. This analysis provides structured units that are easy to understand and discover[90]. Each cluster comprises related keywords within it, which have high similarities. Consequently, clusters provide comprehensive insight into the knowledge structure in terms of the scope of the study (i.e., energy performance).

Citespace was used for conducting cluster analysis within this study to categorize the keywords into groups. There are different algorithms for implementing cluster analysis. However, the log-likelihood ratio (LLR) was chosen for cluster analysis because it provides the highest-quality cluster information in terms of uniqueness and coverage[64]. Figure 9 demonstrates the most significant clusters which CiteSpace generated considering energy performance. Consistently, Figure 9 clarifies the cluster ID, cluster size, silhouette score, cluster label (LLR), mean year, and the representative document for each cluster. The cluster produced by old documents or recent documents was represented by the mean year[92]. The silhouette score displays the cluster's tightness and isolation, whereas the modularity score illustrates intra-cluster connectedness. As a result, the high modularity measure demonstrates high connectivity among the units within the cluster. As shown in Figure 9, the silhouette score for keyword cluster analysis is 0.6422, while the modularity is 0.3292. The estimated silhouette score and modularity amounts demonstrate moderate connectivity and related keywords while moderate separation exists in the intra-cluster[93].

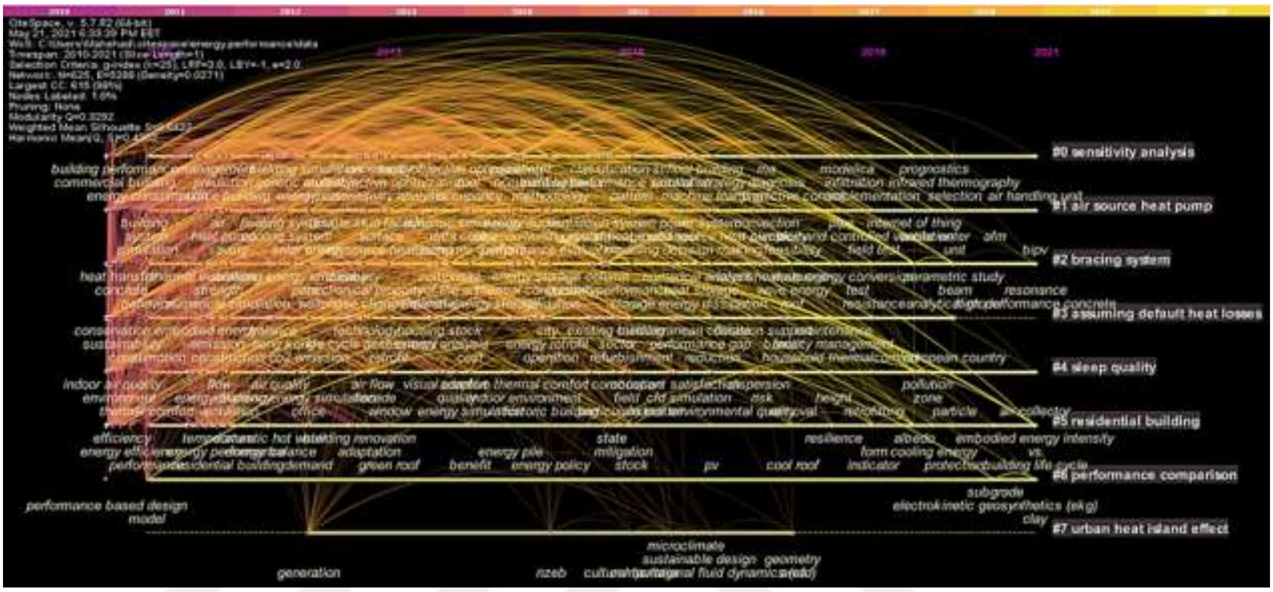


Figure 9. Keyword co-occurrence cluster timeline

The clusters are shown due to their size, which describes the number of keywords in each. Cluster #0, "Sensitivity Analysis", has the most members (117), whereas cluster #7, "Urban Heat Island Effect", has just 11 members (Figure 9). Even though the total silhouette score is moderate, each cluster's silhouette value (Table 6) is high. The high silhouette score for each cluster means high relativity and homogeneity among the keyword within each cluster. The highest homogeneity in this cluster belongs to cluster #6 (silhouette score= 0.987) and follows by cluster #7 (silhouette score= 0.939), cluster #2 (silhouette score= 0.751), cluster #5 (silhouette score= 0.702), cluster #3 (silhouette score= 0.626), and cluster #1 (silhouette score= 0.614). The silhouette score is a measured interval of (-1,1). Thus Cluster#6, Cluster#7, and Cluster #2 are the three most homorganic clusters, respectively (the keywords under the clusters mentioned above are related more than the other clusters.)

For instance some of the keywords under cluster #6 which is labeled by 'performance comparison' with size 11 and mean year of 2019 are different electrode material, occupant behavior, developing countries, building adaptation measure, spray strategy perspective, indirect evaporative cooler, linking human-building interaction, shared office, human perception, public building, visual preference, day lit office, efficient learning, shallow geothermal energy, distribution characteristics, formulating incentive energy policies, cold region, heating energy benchmark, construction project, low-energy building operation, next-generation dedicated outdoor air cooling system, residential building, capturing performance, energy performance, thermal performance, energy efficiency, novel method, office building, energy consumption, building energy, high-rise building ,urban building energy modeling, predictive control, thermal comfort, building energy performance, double skin facade, literature review, construction material, low energy building, indoor environment, spatial analysis, passive building characteristics, living wall system, zero-energy prospect, passive measure, life cycle assessment, Hellenic residential building, building energy efficiency, cool roof membrane, thermo-optic durability, and phase change material inclusion.

Cluster #7 labeled 'urban heat island effect' with size 11 and mean the year of 2016 has the keywords under it such as interior blockage, integrated approach, historical building, decision support system, different world zone, wind-battery hybrid system, energy consumption, life expectancy, particulate air pollution, cool pavements application, cool roof, energy performance, residential building, thermal performance, energy efficiency, office building, building energy, high-rise building, urban building energy modeling, predictive control, thermal comfort, building energy performance, double skin façade, literature review, construction material, low energy building, indoor environment, spatial analysis, passive building characteristics, zero-energy prospect, passive measure, living wall system, life cycle assessment , Hellenic residential building, building energy efficiency, cool roof membrane, thermo-optic durability, phase change material inclusion, corporate facilities, passive design strategies, urban building energy modelling, lumped-capacitance model, future design weather data, thermal-energy performance, subtropical Hong Kong, solar radiation, building form, industrial construction, off-grid container unit, feasibility study, different European cities, building energy demand, urban morphology effect, energy use, characterizing energy-related occupant behavior, economic performance, non-residential building, causality analysis, operational performance indicator, clay-straw building, passive cooling technique, reducing overheating, HVAC system, indoor environmental parameter, designing energy-efficient building, residential apartment building renovation, data-driven method, comparative analysis, comprehensive review, air source heat pump, thermal design, mosque building, ground source heat pump, indoor thermal comfort, occupancy profile, overheating risk, determining post, representative daylight illuminance distribution, heritage building, energy code, thermal insulation material, parametric analysis, heat pump, effect tunnel, novel heating bed system, occupant-centric control, metabolic responses, smart wearable sensor, performance assessment, genetic algorithm, synthetic smart meter data, passive building design, and adaptive energy .

The keywords under the clusters were consistently collected in MS Excel to assess their occurrence frequency. Generally, 800 keywords were under all the clusters evaluated one by one to discover how many times they have been noticed in prior studies/research considering keyword co-occurrence clusters' results. The highest occurrence was three which 36 keywords have occurred in the previous studies where all of them have been used 111 times. The keywords with three frequencies are shown in Figure 10. Besides, some keywords were repeated two times under the clusters. These iterations of these keywords mean the keywords were interesting and got noticed most recently.

By specifying whether the cluster is made up of older or newer documents, the publication years of the documents in each cluster establish the cluster's mean year. Furthermore, a representative document has been chosen for each cluster, and these papers impact the labeling of each cluster. The representative document is chosen by comparing the co-citation frequency of the papers in each cluster, with the document having the highest co-citation frequency being designated as the representative document. It is, nevertheless, critical to cross-reference the clusters with their corresponding papers. Manual control is required when the number of publications included for co-citation analysis grows (51339 valid separate references for this study), and articles are classified based on specific pre-determined parameters (in this example, keywords). 4 clusters (#1, #3, #4, and #6) were not related adequately with their representative document. However, this condition does not cause alarming negative impacts due to the remarkable size of the mentioned cluster.

list of keywords that were repeated three times			
thermal comfort	office building	performance assessment	building energy efficiency
residential apartment building renovation	residential building	reducing overheating	energy consumption
urban morphology effect	operational performance indicator	zero-energy prospect	building form
life cycle assessment	spatial analysis	clay-straw building	Hellenic residential building
solar radiation	passive building characteristics	heat pump	causality analysis
lumped-capacitance model	thermal performance	HVAC system	holistic EPC
thermal-energy performance	passive cooling technique	building energy	characterizing energy-related occupant behavior
non-residential building	thermo-optic durability	high-rise building	corporate facilities
Venetian blind	passive measure	building energy demand	cool roof membrane
list of the keywords that repeated twice			
numerical study	modular-based approach	data-driven method	passive design strategies
comparative study	environmental condition	comparative analysis	urban building energy modeling
air source heat pump	co-occurring formaldehyde	historical building	future design weather data
the-art review	indoor air quality	energy performance	subtropical Hong Kong
bracing system	living wall system	case study	off-grid container unit
phase change material	phase change material inclusion	energy efficiency	different European cities
sleep quality	industrial construction	predictive control	energy use
large machining plant	feasibility study	building energy performance	economic performance
ventilation system	indoor environmental parameter	literature review	green design studio

Figure 10. List of co-occurrence keywords

Hence, irrelevancy between cluster labels and representative documents indicates a weak correlation between the identified cluster and the automatically chosen representative document. Additionally, cluster labeling of some similarities was performed after evaluating the outcomes of the keyword analysis. For instance, cluster #1 is associated with the words ‘ simulation ’, ‘ optimization ’ (Figure 8), and cluster #2 is associated with the words ‘ ventilation ’, ‘ natural ventilation ’ (Figure 8), and cluster #3 is associated with words ‘ Phase change material ’ (Figure 8), and cluster #4 is associated with the word ‘ Heat transfer ’ (Table 6). Cluster #6 is related to ‘energy performance ’, ‘ energy efficiency ’, and ‘ thermal performance ’ (Figure 10). Therefore, other clusters can be correlated with other words depicted in Table 4**,** Table 5, Table 6, Figure 8, and

Figure 9. These interdependencies are useful since cluster analysis constitutes the knowledge domain, and commonly used terms comprise the field's knowledge base. This circumstance also implies that the network's clusters are highly representative.

Table 6. The top keywords cluster

Cluster-ID	Size	Silhouette score	Cluster label (LLR)	Mean years	Representative document
0	*117*	0.546	Sensitivity analysis (280.21,1.0E-4)	2015	Ferrara et al (2014) [94]
1	112	0.614	Air source heat pump (430.48,1.0E-4)	2013	Sarhaddi, F (2010.0) [95]
2	104	0.751	Bracing system (469.49, 1.0E-4)	2015	Xiao, Yan (2010.0) [96]
3	96	0.626	Assuming default heat losses (185.32,1.0E-4)	2014	Gill, Zachary M (2010.0) [97]
4	91	0.568	Sleep quality (172.15,1.0E-4)	2014	Van Den Wymelenberg, Kevin (2012.0) [98]
5	73	0.702	Residential building (170.82,1.0E-4)	2014	Parkinson, Thomas (2020.0)[99]
6	11	0.987	Performance comparison (141.31,1.0E-4)	2019	Hong, Tianzhen (2020.0) [86]
7	11	0.939	Urban heat island effect (106.6,1.0E-4)	2016	Palme, M (2017.0) [100]

Source: data are obtained through cluster analysis via Citespace 0.9.2

3.5. *Findings of Scientometric analysis*

The results of keyword analysis indicate that the keyword energy performance and energy efficiency are among the top 10 keywords, hence the related factors like LEED, roof, envelope, and energy simulation were not getting as much as noticed in previous research. On the other hand, due to the keyword cluster analysis, residential building was not get noticed properly as the silhouette measure for that cluster was the lowest one. It means inter-cluster, there is no proper relativity among other keywords. Therefore, the cluster which addressed comparing performance and the urban heat island effect had the most amount for the silhouette. Under that cluster the following keywords were existing: residential building, high-rise residential building, construction material, envelope material, energy performance, passive cooling, and energy analysis. Consequently, the keyword for implementing the research for this study was recognized. Afterward, in the section below, the literature is reviewed based on the selected keywords, in two groups:

A: ‘energy performance ’, ‘ energy efficiency ’, ‘ building envelope impact ’, ‘ cooling ’, and ‘ high-rise ’

B: ‘ energy performance ’, ‘ energy efficiency ’, ‘ building envelope impact ’, ‘ heating ’, ‘ Design Builder ’, and ‘ high-rise ’

3.6. *Research Background of Building Energy Efficiency*

According to the previous studies, the heating energy demand per floor is 75 (KW/m2) and the cooling energy demand is 41.66 (KW/m2) [4]. Furthermore, between 1973 and 2018, the demand for electricity in buildings increased by 3.8 percent. According to statistics, heating and cooling account for 10% of total energy consumption in buildings [4]. Residential buildings have a significant impact on heating and cooling loads in Turkey, according to Yildiz (2016) [36]. Although the annual energy demand for heating in new and existing residential buildings is expected to fall by 9-29 percent until the 2080s, cooling demand is expected to rise by 1.7-30 percent due to the use of passive cooling strategies.

Sixty percent of the studies investigated within the scope of this research (14 out of 23 studies) were related to the envelope of high-rise buildings, with one being a review paper [83]. Previous research has primarily focused on switchable glazing in high-rise residential buildings[101], the technical, economic, environmental, and comfort implications of new glazing technologies [101], [102], the impact of the thermal bridge of the balcony slab on the envelope [103], the effects of shape coefficient on envelope load and energy consumption [104], the impact of floor-to-ceiling glazed areas on thermal resilience [105], assessing glazing type window-to-wall ratio, sun shading, and roof straying [106], investigating heat transfer through envelope components [106], [107], investigating the efficiency of light-weight and low-energy dynamic insulation, air-tight cavity function, and low-E coating [108], efficient energy codes and insulation materials [109], analyzing double skin brick wall façade and thermal transmittance (U-value) [110], the impact of location and surroundings [111], improving envelope design parameters, optimizing plan layout, and utilizing natural velocity profile[112].

More recent research investigated the impact of the window-to-wall ratio on energy consumption in high-rise buildings using EnergyPlus and Octopus [113]. Similarly, Yik et al. (2006) implemented energy simulation via EnergyPlus considering building shape and layout by switchable glazing to assess the cooling electricity demand [112]. Moreover, Bahaj et al. (2007) explored the emerging technologies for glazing intending to control energy consumption through the computer array model to simulate air-conditional load and conduct transient thermal analysis [114]. Ge et al. (2013) analyzed the impact of balcony thermal bridges on thermal performance through 2D heat transfer simulation [103]. Furthermore, Raji et al. (2016) sought an energy-saving solution by comparing refurbished existing buildings using Design Builder [106]. Furthermore, Kalhor and Emaminejad (2020) used a questionnaire and the COMcheck tool to conduct both quantitative and qualitative research on insulation thermal optimization and the market [109]. Abdul Nasir and Sanusi Hassan (2020) investigated the thermal performance of double brick walls (opaque and transparent) using U-value and overall thermal transfer value [110]. Dincer and Mihlayanlar (2020) used DesignBuilder and EnergyPlus to analyze the air corridor façade of Turkey's tallest building to reduce its cooling and heating demand [26]. Through sensitivity and regression analyses, Chen et al. (2021) aimed to provide comprehensive and reliable simulation on air conditioning, lighting, and the envelope feature in order to develop Net Zero Energy Building [24].

CHAPTER IV

RESEARCH RESULTS AND DISCUSSION

4.1. Analyses

Within this research, two different groups of analyses were performed to evaluate the impact of each scenario on heat gain/heat loss. Heating and cooling design analyses were conducted about cooling/heating design capacity, sensible cooling /heating, and zone sensible cooling/heating. The cooling and heating design were assessed concerning ASHEARA 90.1 standards and standards of Turkey. The analyses were conducted according to the wall structures, wall-to-window ratio, and site orientation. The efficient scenarios were opted for following analyses in terms of floor, roof, and glazing types.

4.2. Heating Analyses

Within the scope of this research, the heating design analyses were performed for a 10-story residential building located in Istanbul, Turkey. The heating design analysis aims to get information about the heat gain /loss of building components/materials and the heat design capacity/total design heating capacity. The vaster surface area of the reference building was placed face to the north/south. According to Lotus and Poyraz's wind directions, which are primarily from East North and West North, the north side of the building gained more interest in this study.

The variables considered for building design are as follows: total design heating capacity(kW), steady-state heat loss(kW), external infiltration (W/sqm), and sensible zone heating(W/sqm). The outputs of these variables for reference building were 331,75 (kW), 26,54(kW), -23,17 (W/sqm), and 49,15(W/sqm) (Figure 11). According to the results of reference building, external infiltration, external vent, glazing, and walls were the components/factors that had heat more witnessed (Figure 11).

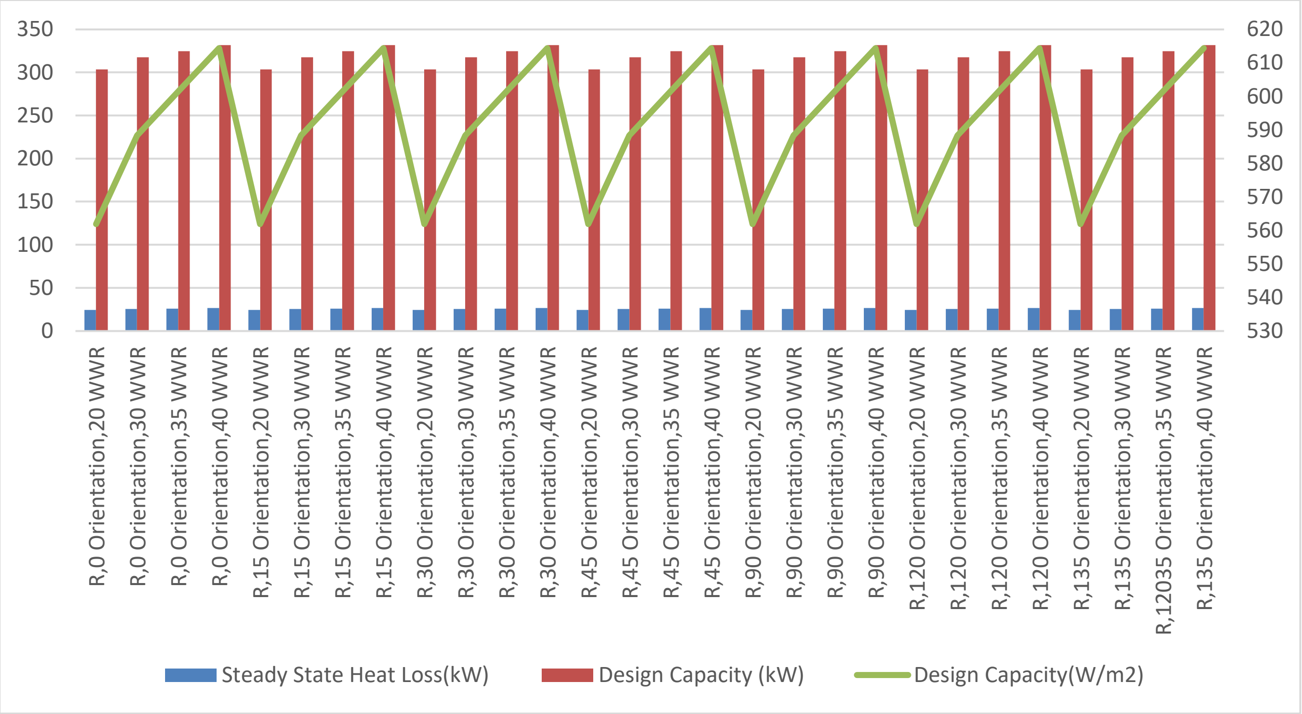
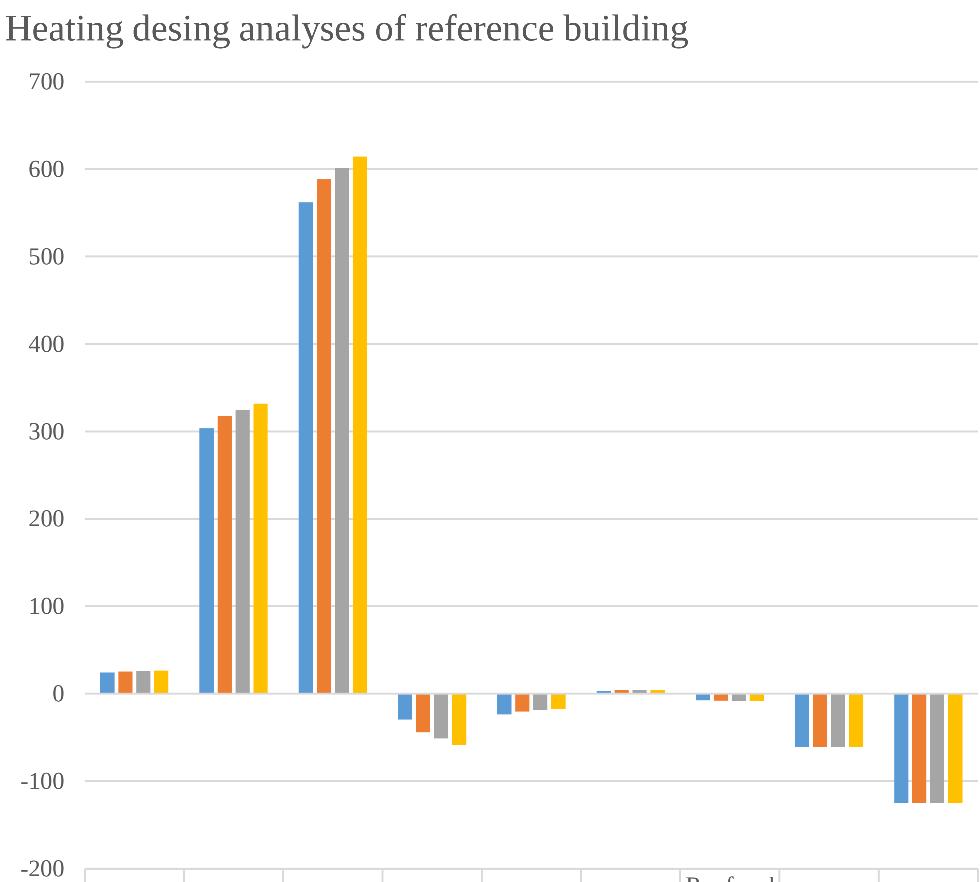


Figure 11. Reference building's scenario heating design analyses results

Heating design analyses were performed regarding various orientations (0,15,30,45,90,120,135) and window-to-wall ratio (20%, 30%, 35%, 40%) for reference building template. The results of heating analyses were evaluated and illustrated in Figure 12. The reference building, which was assumed as the first model, was designed with a 40% wall-to-window ratio and 0-degree orientation to the North. According to the obtained results, design capacity has decreased concerning the reduction of WWR while the heat gain through walls has increased. Furthermore, glazing, roof, and floor heat gains have decreased. It is noteworthy that the ventilation and infiltration heat gain didn't get changed for different window-wall- ratios. Besides, the evaluation of each orientation regarding different window-to-wall ratios indicates the same results for the considered measurements (design capacity, glazing, wall, roof, floor, ventilation, and infiltration heat gain/loss). The breakdown of temperature and heat loss for the reference building (scenario R,0,40%) are illustrated in Figure 12.



	steady-state heat loss(kW)	Design Capacity (kW)	Design Capacity (W/m2)	Glazing Gains (kW)	Wall Gains (kW)	Floor Gains (kW)	Roof and Ceiling Gains (kW)	Ventilati on Gains (kW)	Infiltrati on Gains (kW)
reference building, o Orientation, 20%WWR	24,275	303,44	561,9168	-29,45	-23,62	3,4	-7,43	-60,51	-125,11
reference building, o Orientation, 30%WWR	25,41	317,7	588,3152	-44,06	-20,5	3,98	-7,97	-60,51	-125,11
reference building, o Orientation, 35%WWR	25,981	324,73	601,3868	-51,28	-18,96	4,27	-8,23	-60,51	-125,11
reference building, o Orientation, 40%WWR	26,543	331,75	614,3756	-58,46	-17,43	4,55	-8,48	-60,51	-125,11

reference building, o Orientation, 20%WWR; reference building, o Orientation, 30%WWR; reference building, o Orientation, 35%WWR; reference building, o Orientation, 40%WWR

Figure 12. Evaluation of heating design analyses for reference building’s scenario

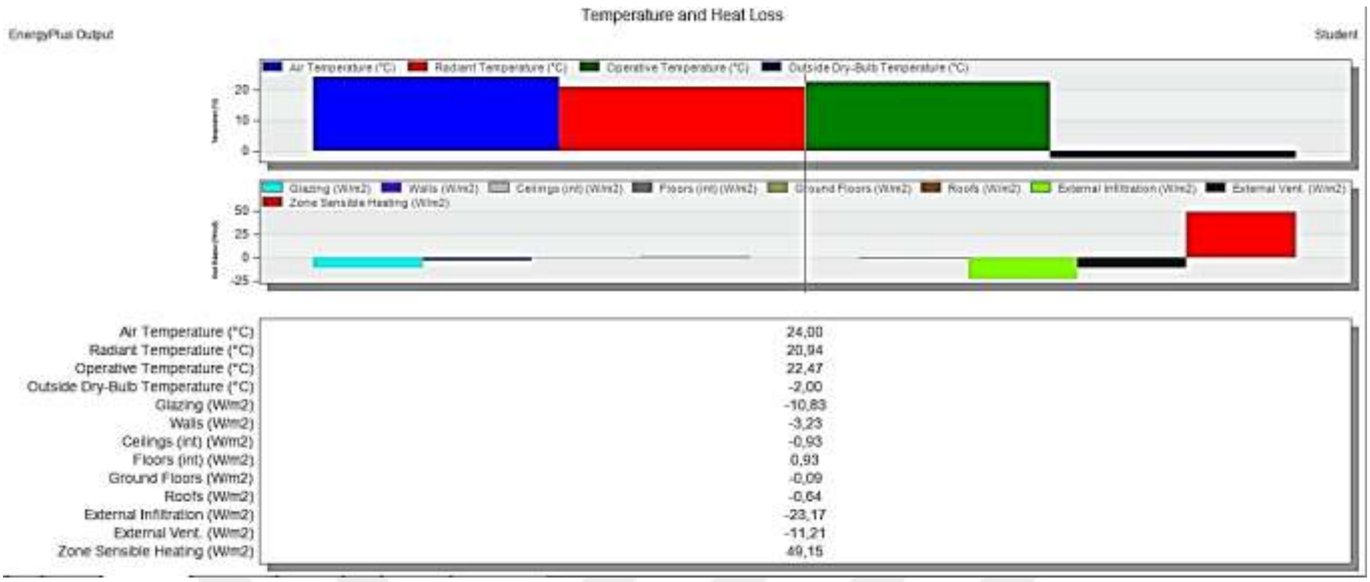


Figure 13. Heating analysis of reference building with zero degrees' site orientation and 40% WWR

As it is shown in Figure 13**,** glazing and wall have higher heat loss amounts than other components. The infiltration and vent have remarkable heat loss as well. In the further steps, the curtain wall's scenario and timber wall's scenario have been evaluated respectively.

Heating design analyses were conducted according to curtain wall template criteria with the same variables (area, building shape, In the first scenario, the total heating design capacity decreased to 481,43 and followed the other variables (Steady-state heat =23, sensible zone heat=36, external infiltration = -14) (Figure 14). Significant change addressed the influence of the external wall, surface wall, and grade below walls on heat load. The results of the heating analysis are shown in Figure 12. Even though results are different in a small range, it was highly notable to consider the difference in heating design capacity among floors. The third template for wall equipment is a super-insulated timber frame wall. The outputs of heating analysis for each floor heating design capacity demonstrated the wide range of differences between the two last floors and other floors.

The heating design capacity for lower floors was interval 15-21 while this measure was interval 60-80 for the two last floors (floor 9,10).

The four variables mentioned above (total design heating capacity(kW), steady-state heat loss(kW), external infiltration (W/m2), and sensible zone heating(W/m2)) in each analysis were approximately the same. In contrast, the external air infiltration and steady heat loss gave remarkably different results in range. For instance, external air infiltration was mostly -14 while it was -2,80 for Timber frame wall components.

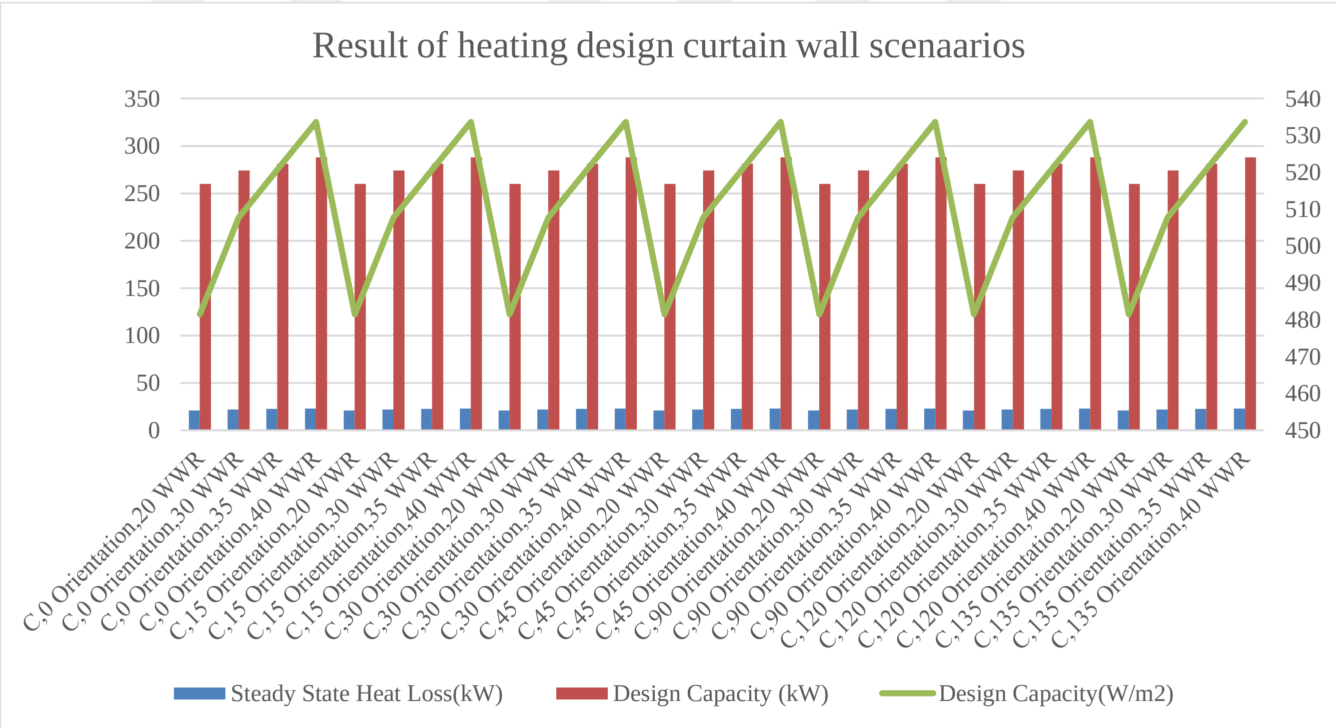


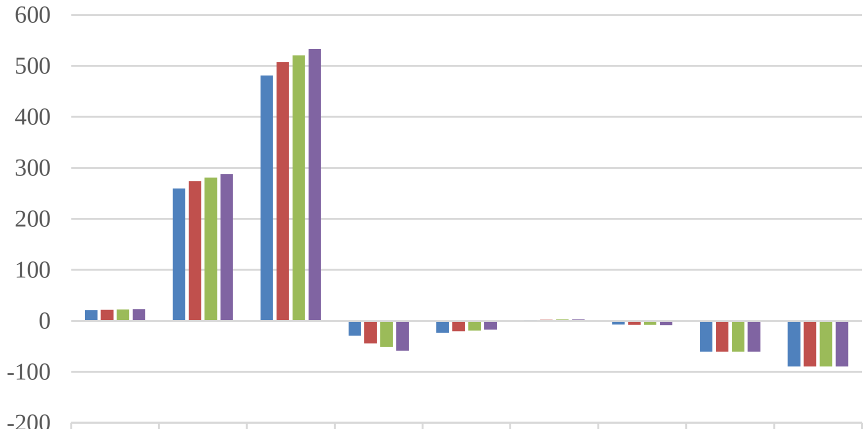
Figure 14. Curtain wall scenario heating design analyses results

On the other hand, heating design capacity and heat loss remarkably changed in scenario C15-30. The curtain wall structure composes 4 layers named brickwork outer, XPS extruded Polystyrene, concrete block, and Gypsum plastering. These combinations provide sufficient insulation for the envelope of the building resulting in the reduction of heat loss, zone sensible heat, and heating design capacity.

The interaction of design capacity, steady-state heat loss, infiltration and ventilation heat gain/loss of curtain wall's scenarios are indicated in Figure 15. There is a direct interaction between WWR ratio and steady-state heat loss, design capacity, and heat gain/loss through glazing and wall. Notable indirect interaction observed between glazing and wall heat gain/loss according changing the WWR ratio. Additionally, it's worth noting the amount of infiltration and steady-state heat gain/loss got decreased approximately by 12% rather to the reference building results.

15-30 degrees' orientation in site location provides good placement for building both for sunlight and facing wind direction. Consequently, the smaller surface of the building faces wind direction and breaks the wind speed acting as a windbreaker that results in controlling thermal mass transmission on the surface of the building. Hence, the results are the same for the other orientation. Ninety degrees are the most influential as it changes the vaster surface with the smaller surface of the building, which is faced with the wind.

Moreover, WWR on the north side of the building influence the head design capacity remarkably. By implementing 35% and 30 % WWR in the reference model, the results of heating analyses are more efficient in energy consumption.



	steady-state heat loss(kW)	Design Capacity (kW)	Design Capacity (W/m2)	Glazing Gains (kW)	Wall Gains (kW)	Floor Gains (kW)	Roof and Ceiling Gains (kW)	Ventilation Gains (kW)	Infiltration Gains (kW)
curtain wall building, o Orientation, 20%WWR	20,798	259,97	481,4315	-29,43	-23,39	1,7	-7	-60,51	-89,36
curtain wall building, o Orientation, 30%WWR	21,933	274,15	507,6908	-44,06	-20,3	2,4	-7,56	-60,51	-89,36
curtain wall building, o Orientation, 35%WWR	22,494	281,18	520,6958	-51,24	-18,78	2,76	-7,83	-60,51	-89,36
curtain wall building, o Orientation, 40%WWR	23,052	288,17	533,6199	-58,41	-17,26	3,1	-8,13	-60,51	-89,36

Figure 15. Evaluation of heating design analyses for curtain wall's scenario

The heating design analyses results for timber wall's scenarios were assessed and compared as well. The illustration of heating analyses for timber wall scenarios is shown as Figure 16. The lowest heating design capacity is observed in scenarios T15-35, and T30-30 which is 250 (the result for the reference building is approximately 280 kW). It is crystal clear that superinsulation walls impact the results widely, but the problem is with the higher floors in the building, which gain higher heat and lose more heat than lower floors. For the scenarios, the highest heat loss is for the roof's external vent, while other factors have decreased very well.

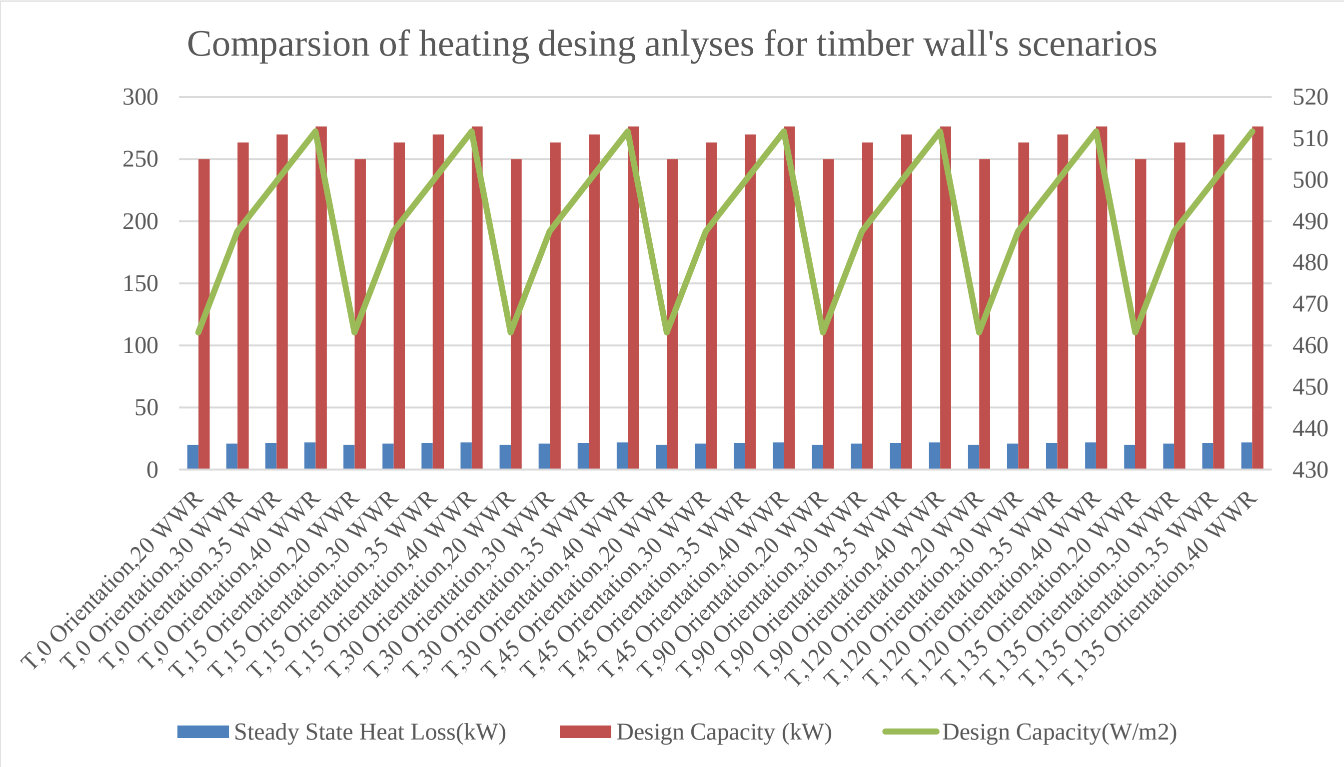
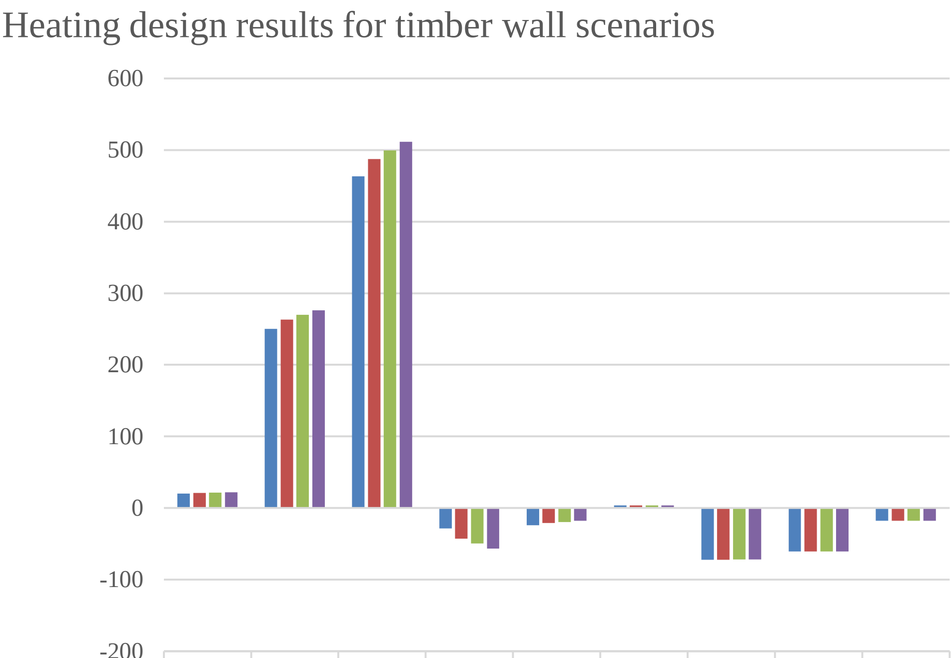


Figure 16. Timber wall scenario’s heating design analyses results



	steady-state heat loss(kW)	Design Capacity (kW)	Design Capacity (W/m2)	Glazing Gains (kW)	Wall Gains (kW)	Floor Gains (kW)	Roof and Ceiling Gains (kW)	Ventilation Gains (kW)	Infiltration Gains (kW)
timber wall building, o Orientation, 20%WWR	20,01	250,12	463,1667	-28,56	-24,17	3,43	-72,41	-60,51	-17,87
timber wall building, o Orientation, 30%WWR	21,063	263,29	487,5707	-42,72	-20,98	3,6	-72,17	-60,51	-17,87
timber wall building, o Orientation, 35%WWR	21,58	269,82	499,66	-49,73	-19,41	3,7	-72,05	-60,51	-17,87
timber wall building, o Orientation, 40%WWR	22,106	276,31	511,6772	-56,69	-17,86	3,78	-71,94	-60,51	-17,87

timber wall building, o Orientation, 20%WWR; timber wall building, o Orientation, 30%WWR; timber wall building, o Orientation, 35%WWR; timber wall building, o Orientation, 40%WWR

Figure 17. Evaluation of heating design analyses for timber wall's scenario

The reduction of heat loss through infiltration is remarkably noting for timber wall scenarios. The heating design analyses were evaluated and shown in Figure 17. The amount of heat loss through infiltration has decreased remarkably when compared to the curtain wall and normal structures. Consequently, it is proved that timber wall scenarios are high potential in preventing heat loss that results in significant reduction of heat loss/gain amount through building envelope components.

Furthermore, the CO_2 embodied for three kinds of material used throughout the analysis was considered and evaluated to identify the interaction between the envelope material and embodied CO_2. Embodied CO_2 was equivalent to 259249 (Kg co2), 248741 (Kg co2), and 339924 (Kg co2) for reference template, curtain wall template, and timber frame wall template, respectively. The reason for the high amount of embodied CO_2 in timber frame walls is because of XPS extruded polystyrene. These results prove the crucial role of insulation and its impacts on building energy efficiency as well as the environment.

4.3. Cooling Analyses

The cooling analyses were conducted to compare cooling design capacity and cooling demand for three different types of building envelopes. Within this scope, different combinations of wall material types (i.e., timber wall, reinforced concrete wall, and curtain wall), various site orientations, and different WWR were evaluated by considering the wind directions in Istanbul, Turkey. Simulation results show that the cooling design capacity for the reference building concludes 429.67 kW which refers to sensible cooling and cooling load. According to the results, the cooling load and sensible cooling decrease on lower floors and increase on higher floors. Hence, it was worth noting that the last floor has a lower amount of cooling load rather than the 9th floor. Furthermore, the flow rate for the reference building is in the range of 19.76 m3/s. Design flow rates demonstrate the flow required to provide sensible cooling. Comparing the results of design flow rate and sensible cooling per floor shows that the height of the building is not the only influential factor. The sensible cooling amount increases between the 3rd and

9th floors (9 m – 27 m) while the improvement in design flow rate occurs between the 5th and 9th floors (15 m - 27m).

4.3.1. Cooling Analysis of Reference Building

The U-value for the project template component was defined by typical reference data modified while the component was loaded. The U-value for the project flat roof is 0.25 (W/m2K), for the project internal floor is 2.92 (W/m2K), for the wall typical reference lightweight is 0.34 (W/m2K), for the project ground floor is 0,25 (W/m2K), and for glazing is 1.96 (W/m2K). Building data composes of building heating/cooling floor area (5400 m2), building volume (18900 m3), building external area (4370 m2), building area-weighted average U-value (0.888 W/m2K), and building external surface area /volume (0.231 m-1). Site orientation was assumed to be zero degrees and the window-to-wall ratio was 40% (Table 7).

The results are substantial as the time of maximum cooling load was 17:30 in July. On the other hand, the minimum design capacity amount was 40.7 kW for the ground floor which was followed by the 1st floor (42.5 kW). Floors between the 2nd floor and 8th floor are in the same range approximately between 43.14 - 43.65 kW while the 9th floor is 42.17 kW which has a lower design capacity than the 2nd floor. Meanwhile, the total cooling load for the first floor is found to be 35.39 kW, which is the lowest amount followed by the 2nd floor at 36.96 kW, while for other floors it is between 37.5-37.9 kW. Notably, the 9th-floor cooling load is 36.6 kW. The total cooling load for whole the building is 373.63 kW. The outside dry-bulb temperature at the peak time of cooling load is 24.28 ºC and the maximum operating temperature during the day is 32.9 ºC with 48.8% humidity for the whole building. The highest heat loss for floors is -44.22 kW (negative corresponds to heat loss) followed by roofs and ceilings (-21.04 kW), walls (-9.75 kW), infiltration (-7.87 kW), and glazing (-6.8 kW). Details of the results are shown in Table 7 and Figure 18.

Table 7. Envelope component for the reference building

Envelope component of the reference building	**U-Value (including bridging) (W/m^2K)**
Project flat roof	0,25
Project internal floor	2,929
Wall - Typical reference – Lightweight	0,347
Project ground floor	0,25

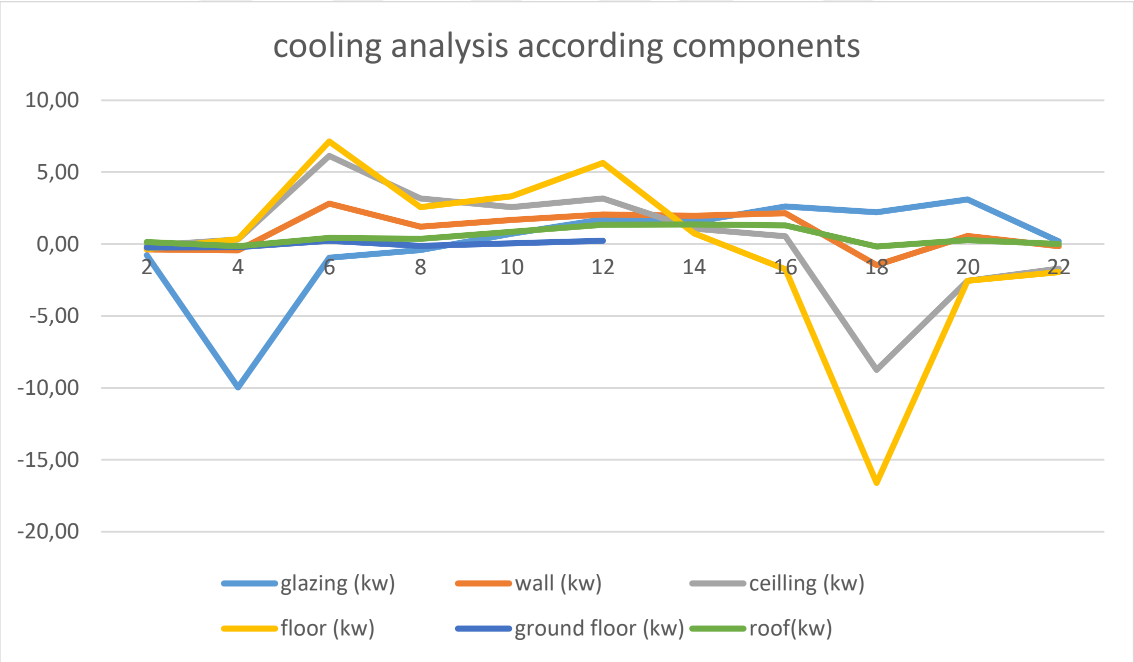


Figure 18 . The result of cooling design analyses for reference building regarding components

According to Figure 18, among building components, floors gain significant heat during the daytime. The maximum heat gain occurs at 5:30 am which corresponds to relative humidity at the same time. The outside dry bulb temperature impacts heat loss for the floor at 5:300 pm. Meanwhile, glazing at 5:30 pm gains more heat than other components. Notably, glazing, roof, and ground floor have a more limited temperature range of change than the other components. Accordingly, floors, ceilings, and walls have a large range of changes for heat gain/loss, respectively. As the U-value for floors is 2,929 consequently the heat gain and heat loss occur in a vast range. On the other hand, these results prove the impact of thermal conductivity and heat transfer of materials in terms of gain/loss of heat. The thermal mass of materials is one of the other important factors considering the high-temperature difference is very influential upon heat transfer.

The mean of mean radiant temperature and mean internal temperature is the operative temperature. The operative temperature and relative humidity act in opposite directions between 6:00 a.m. and 6:00 p.m. Figure 19 shows a significant increase in total cooling, sensible cooling, and zone sensible cooling. The maximum sensible cooling is reset, as is the latent load, which can be the same as the sensible cooling load if the latent is negative. As shown in Figure 19, total cooling and sensible cooling use about 50 kW between 6:00 am and 6:00 p.m., whereas before 6:00 am and after 6:00 pm, they use about the same amount. It means that latent load before 6:00 am and after 6:00 pm is negative and ignored in the analysis. Latent is the latent load for the zone at the time of maximum sensible load. The long dash in Figure 20 indicates the linear forecast for total cooling load, which increases in the daytime. In addition, zone sensible cooling load is the sensible cooling that impacts the zone of any free air introduced internally. Moreover, the sensible cooling load and zone sensible load are interrelated. This means the design flow rate and sensible cooling are matched properly.

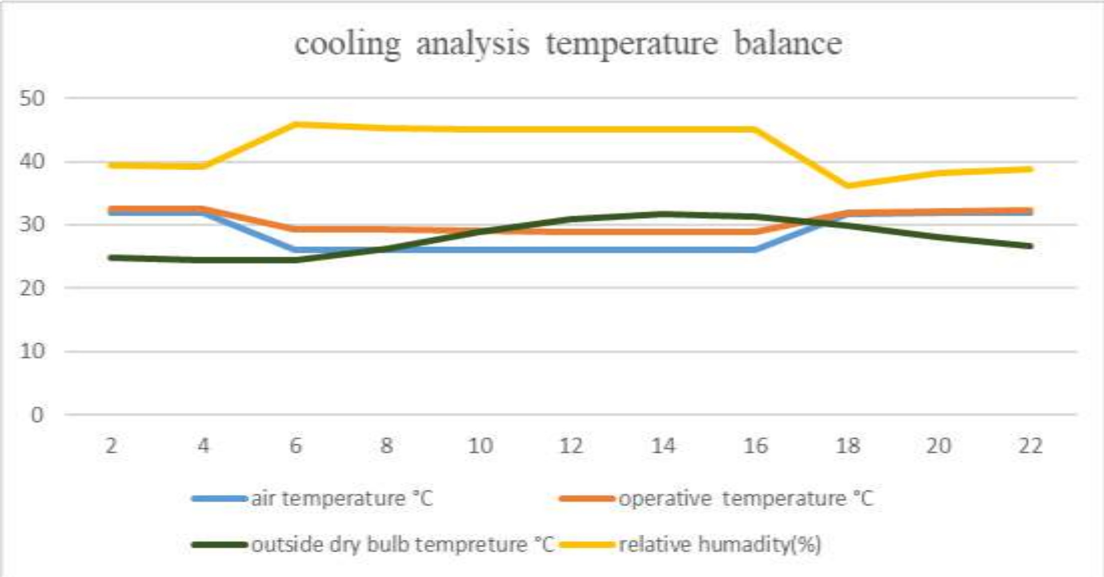


Figure 19. The results of cooling design analyses of reference buildings regarding temperature

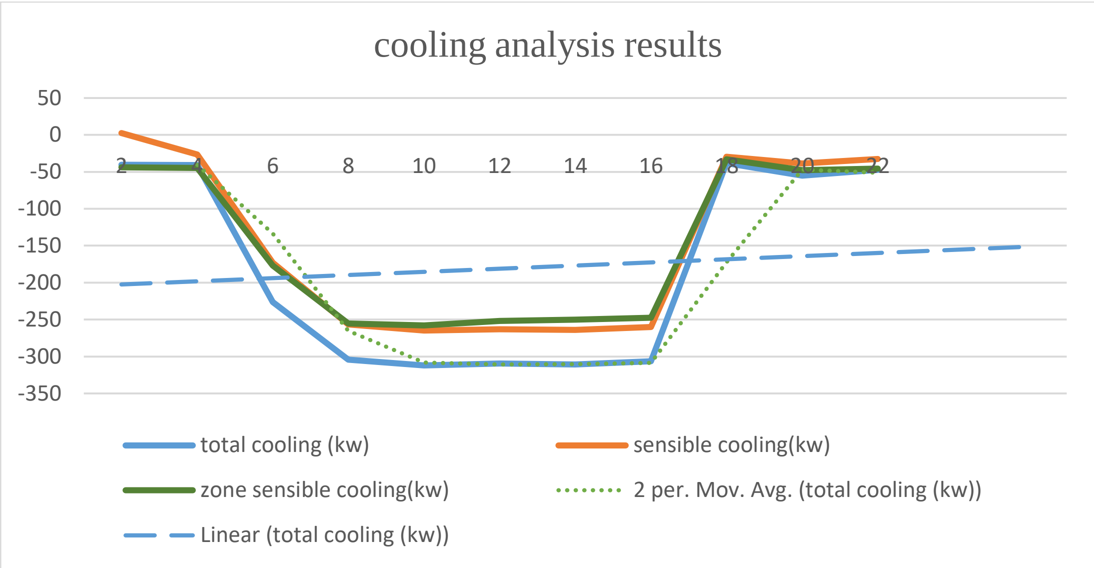


Figure 20. The results of cooling design analyses for the reference building

4.3.2. Cooling Analysis of Curtain Wall

Design capacity for scenario C-3 (curtain Wall, 30% WWR, zero site orientation) equates to 438.27 kW. The design capacity of the 1st floor is 36.65 kW, the 2nd floor is 40.69 kW, 3rd floor is 43. 07 kW, 4th floor is 43.77 kW, 5th floor is 43.95 kW, 6th floor is 44.04 kW, 7th floor is 44.09 kW, 8th floor is 44.24 kW, 9th floor is 44.34 kW, and 10th floor is 43.95 kW. The total cooling load is 372.41 kW while the lowest amount belongs to the 1st floor with 31.87 kW followed by the 2nd floor with 35.38 kW. The total cooling amount for floors between the 3rd floor and the 9th floor are intervals of 37.45-38.56 kW while the total cooling amount for the 10th floor is 37.81 kW.

Figure 21 and Figure 22 demonstrate the interaction between building envelope components and air temperature, relative humidity, and dry bulb temperature. The results are in the neighboring range; therefore, subsequent results of scenarios are significantly influencing cooling energy demand while providing thermal comfort. Scenario 7 (Curtain wall template, 15-degree rotation site location, and 30% WWR) has the minimum design capacity which means minor energy demand for cooling (Figure 10). The second efficient scenario is scenario 8 (curtain wall template, 30-degree rotation site location, and 30% WWR) which follows scenario 15 (curtain wall template, 120-degree rotation site location, and 35% WWR). According to the results, the relation between design flow rate and design capacity was discovered; while the design capacity is increased design flow rate increase simultaneously.

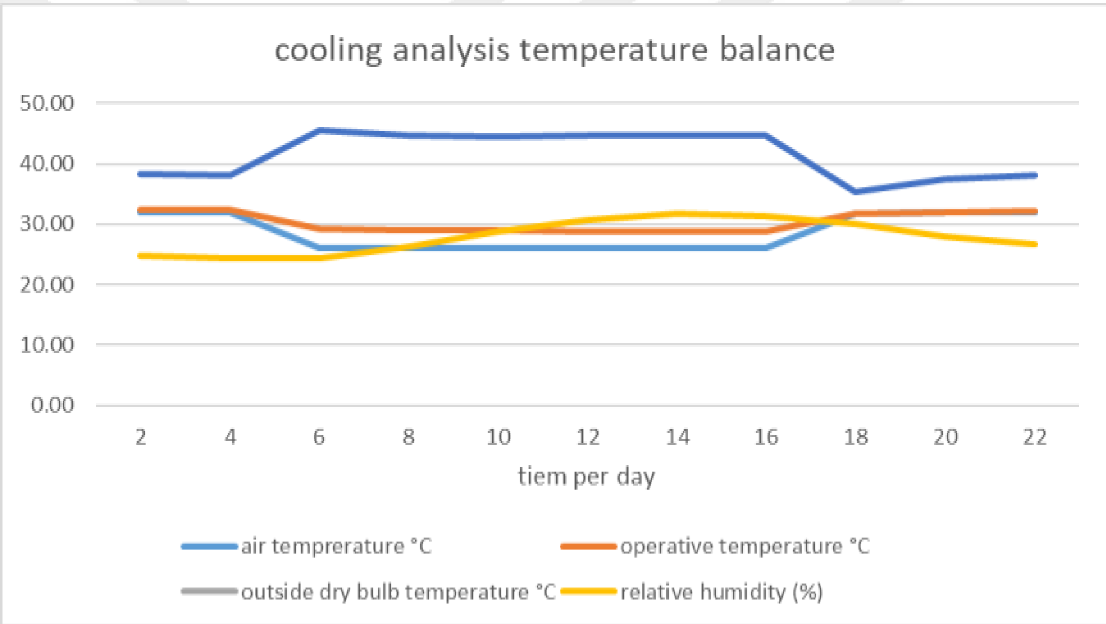


Figure 21. The results of cooling design analyses for curtain wall’s scenario regarding temperature

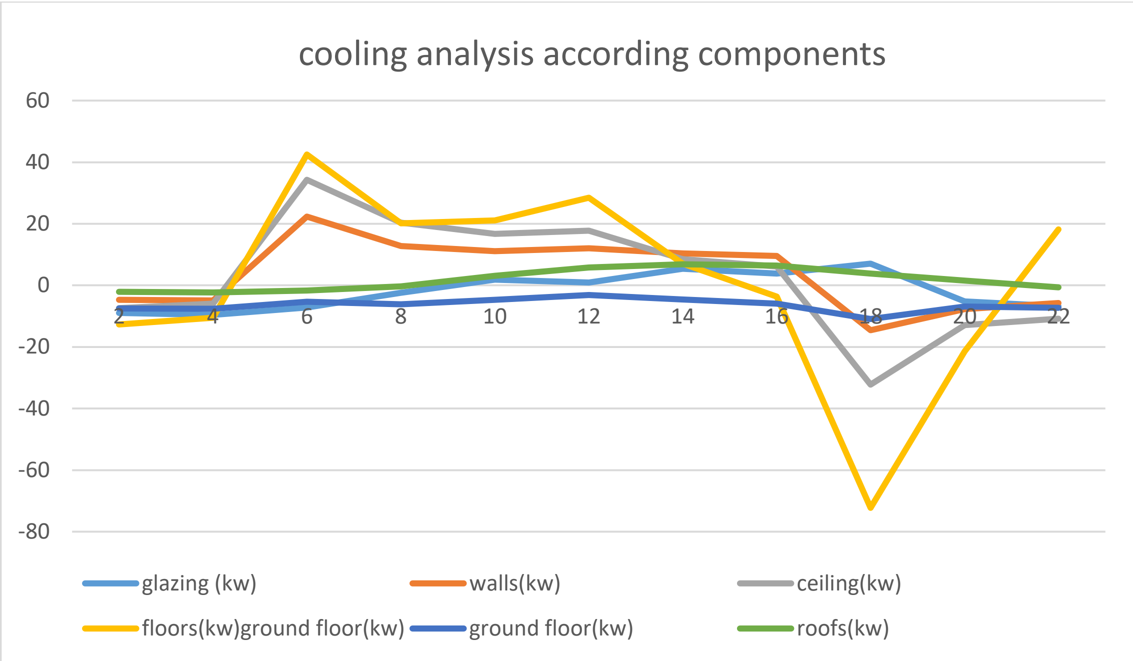


Figure 22. The results of cooling design analyses for curtain wall's scenario regarding components

As the initial point for comparing the curtain wall scenarios with the reference building, there is a little difference between the temperature balance chart for the curtain wall and the reference scenario (Figure 19 and Figure 21). However, there is an important difference in the cooling analysis results based on building components. Same as the reference building, floors, ceilings, and walls have a great range of change for heat gain/loss while the slope of increase/decrease is more moderate than in the reference building. As the material of the floors is the same for all the scenarios, the influence is not clear, therefore, walls have a moderate slope per daytime. The maximum amount of heat gain for walls is equal to 22,37 kW, and for the reference building 22, 22 kW. The lowest amount for the same scenario is -10,32 kW while it is around -14,34 kW for the reference building. Concerning Figure 19, heat gain at 8 a.m., 10 a.m., 12 p.m., and 10 p.m. decreases by 2kw in the reference building at the same time. The component's heat gains reduction results in decreasing cooling demand. Figure 23states this fact indicates a 14 kW reduction in total cooling load at maximum outside dry bulb temperature. The long dash in Figure 23 is an ascending linear forecast line however there is a slight reduction in cooling load. The cooling design analyses for curtain wall scenario are demonstrated in Figure 24.   .

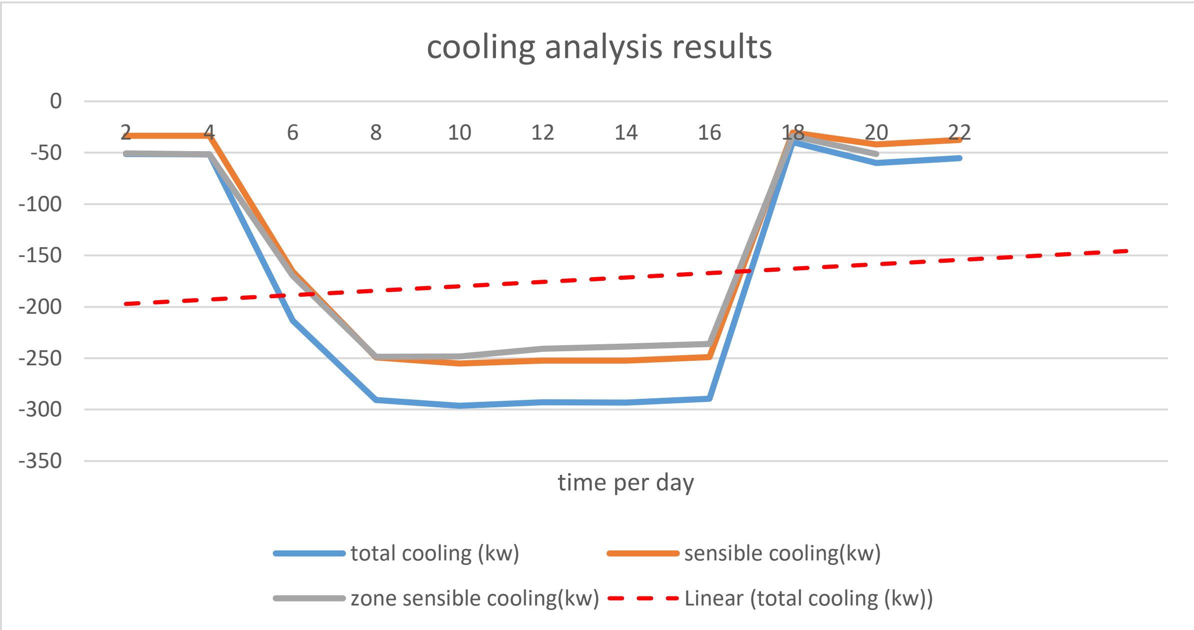


Figure 23. The results of cooling design analyses for curtain wall

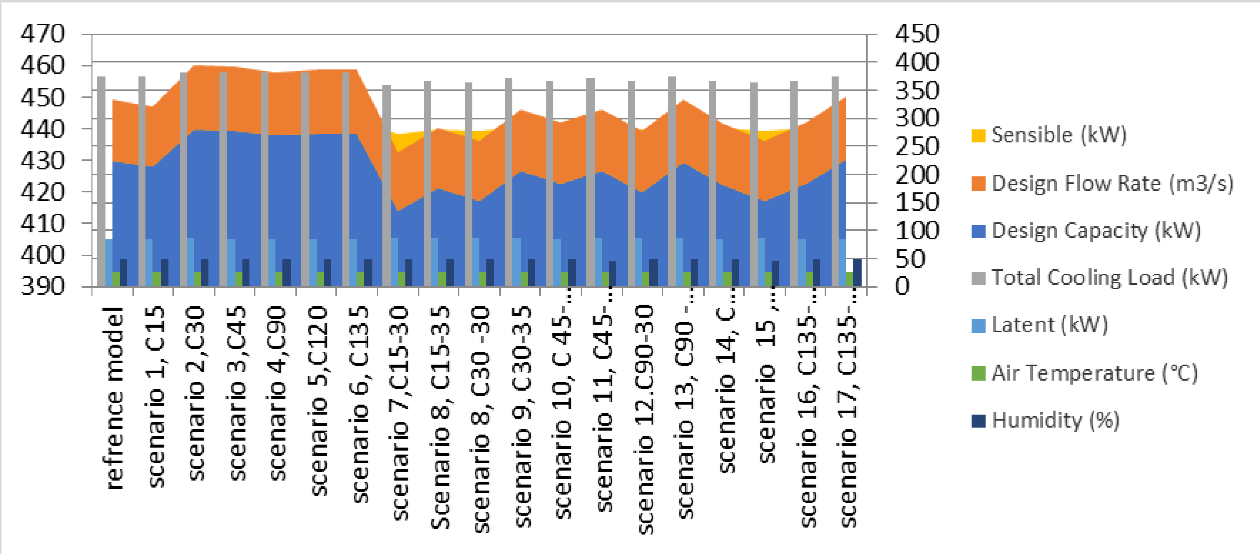


Figure 24. The results for cooling design analyses of the curtain wall scenario

4.3.3. Cooling analysis of timber wall

The third template wall structure is supposed to be a super-insulated timber frame wall. According to Figure 11, a noteworthy difference between Figure 25 and Figure 19 is observed. The linear forecast line is approximately straight, and the amount of total cooling load is around 200 kW. The results of timber wall scenarios address a reduction in dry bulb temperature for each floor except for the last floor, which increases by 6 °C. Besides, the relative humidity percentage decreases for each floor by 2-3 °C (Figure 26). The air temperature, operative temperature, and Dry-Bulb temperature are not as high as the aforementioned templates interval 4:00-6:00 pm (Figure 5, Figure 7, and Figure 12) and there is an intersection at 6:00 p.m. The problem here is about the last floor of the building which has remarkable heat gain due to the low air infiltration needs to the higher amount of design flow rate. The reason for the higher total cooling load is because of the last floor (Figure 11). The maximum cooling load occurs at 2:00 pm while at the same time the amount of heat conductivity gained by the roof is higher between 10:00-2:00 pm (Figure 13). The most heat gain occurs on roofs, floors, glazing, and walls, respectively.

This is because of observing higher sensible temperatures in these scenarios rather than curtain wall scenarios. For example, Scenarios 24 (timber frame, 15-degree orientation, 30% WWR), 26 (timber frame, 30-degree orientation, 30% WWR), and 30 (timber frame, 90-degree orientation, 30% WWR) are the most efficient scenarios with the lowest cooling design capacity, respectively (Figure 14).

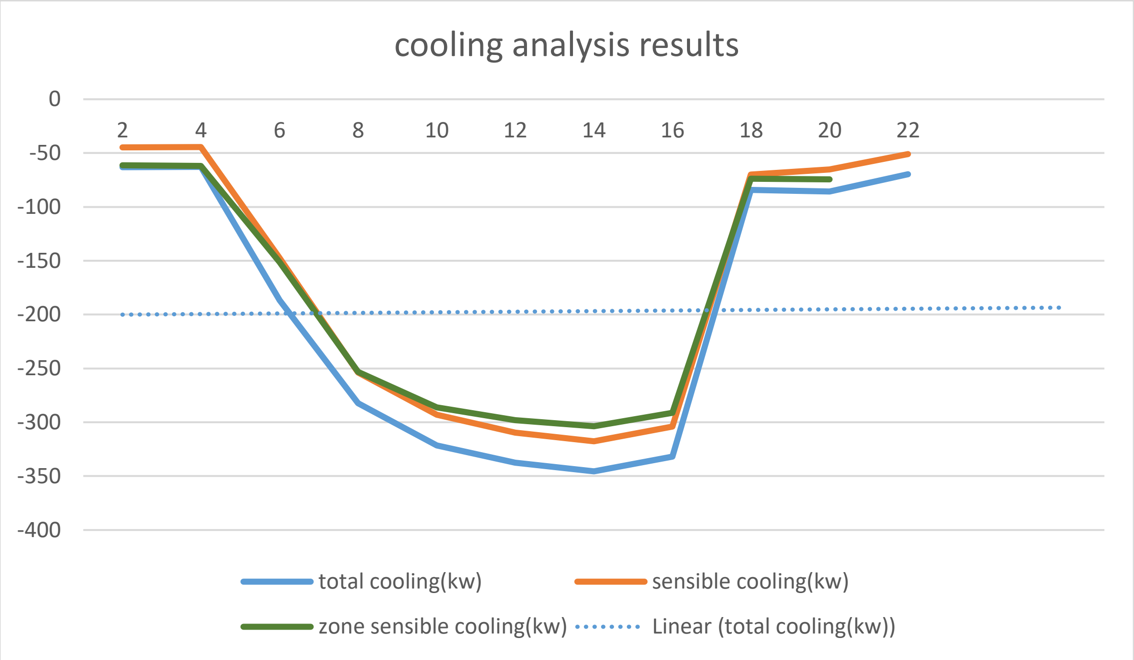


Figure 25. The results of cooling design analyses for timber wall

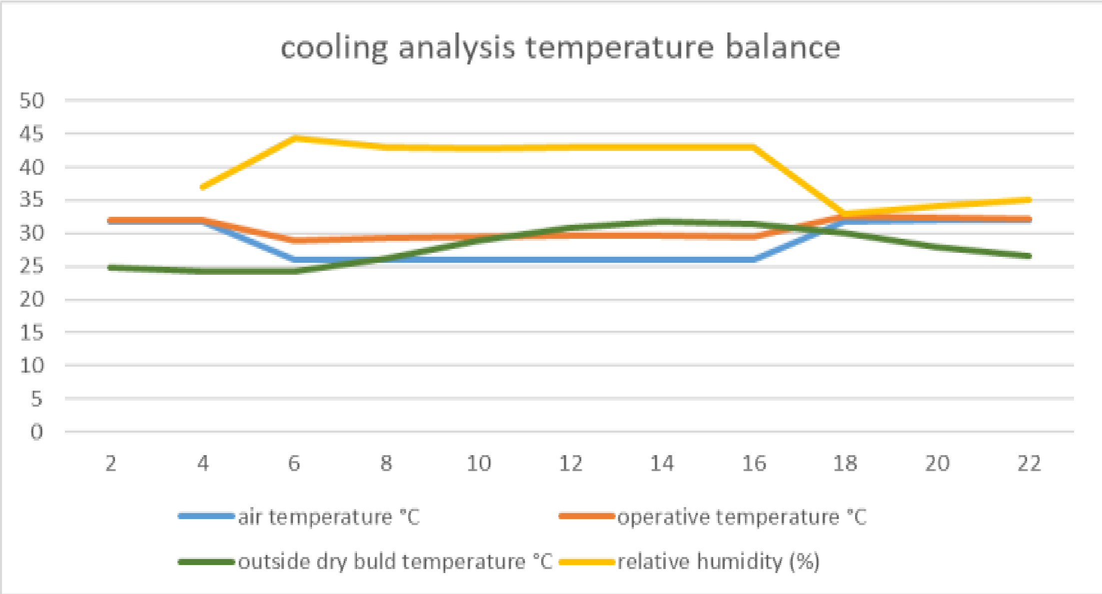


Figure 26. The results of cooling design analyses for timber walls regarding temperature

Figure 27 indicates that the heat gain and loss through wall, glazing, ceiling, and ground floor decrease significantly in comparison with Figure 22 and Figure 18. Even though floor heat conductivity gain/loss decreases remarkably for the daytime except at 12:00 pm and 6:00 pm. The heat gain through the floor means the zone below is colder. As the roof gains solar radiation and longwave gains heat much more than other components. On the other hand, the air infiltration is insignificant in the super-insulation walls (i.e., timber walls) which increases the heat gains of the last floor. This means the total cooling loads for the last floor increase assertively. The cooling design analyses of timber wall scenarios are demonstrated in Figure 28 according to the considered variables (i.e., cooling design and sensible cooling).

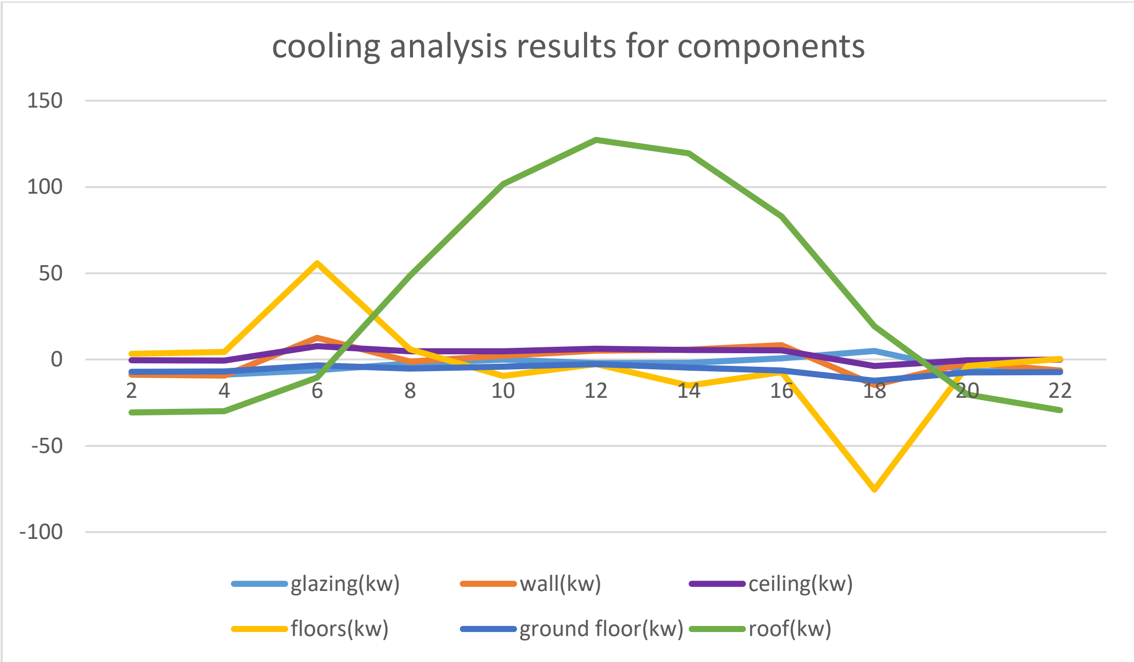


Figure 27. The results of cooling design analyses for timber wall's scenario regarding components

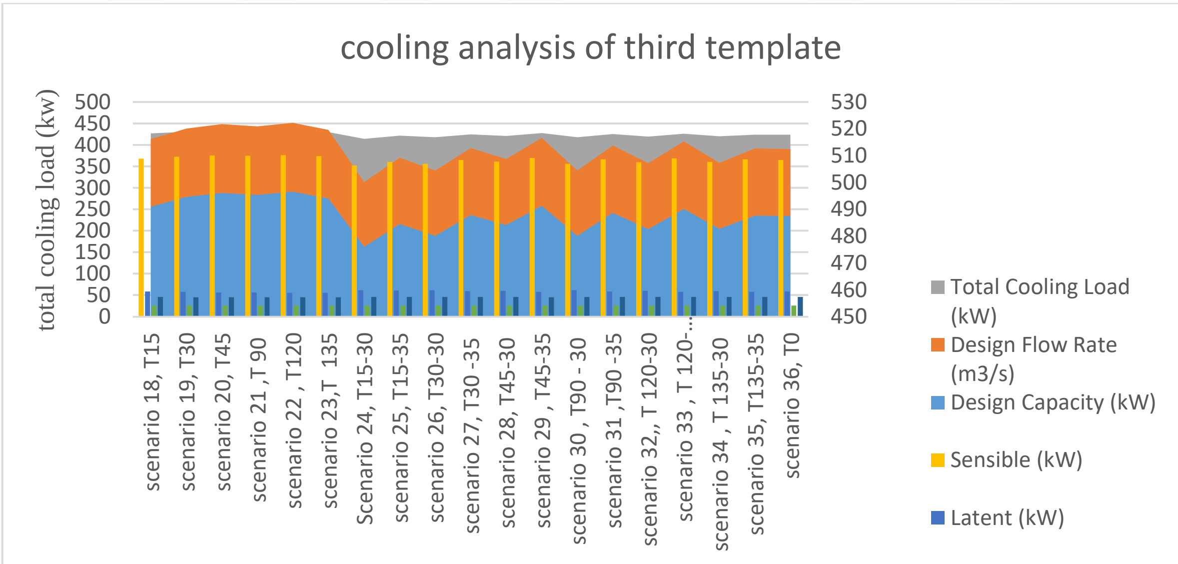


Figure 28. The results for cooling design analyses of timber wall scenario

CHAPTER V

CONCLUSION

This study (1) builds up a knowledge base for exploring the optimal building envelope components based on the relevant aspects of energy performance to design energy-efficient high-rise buildings and (2) analyzes and compares the effects of three different building envelope materials (i.e., reinforced concrete, timber wall, and curtain wall) on energy performance in a high-rise residential building. For this purpose, first, Cite Space, VoSViewer, and Gephi were used for building up a knowledge base in building energy performance. Then, various scenarios for evaluating the impact of envelope components (e.g., wall structure, window-to-wall ratio, and site orientation) were developed and analyzed. Efficient scenarios were opted for developing analyses in terms of floor, roof, and glazing type to decrease the heat loss/gain in the roof, floor, and glazing. Passive strategies, including building shape, orientation, insulation, and window-wall ratio, were implemented in a 10-story residential building in Istanbul, Turkey. Design-Builder was used for analyzing and comparing the energy performance of the different wall, insulation, and glass materials used in the building.

Findings show that using proper sustainable materials for building envelopes and façades as well as arranging the building orientation and the window-to-wall ratio (WWR) provide the same situation of influential factors on heat demand. According to the outputs of heating analyses, curtain walls and timber walls reduce heat demand in buildings and decrease external air infiltration significantly. The only problem is that the timber wall frame, due to super-insulated higher floors, receives too much heat related to the high measure for cooling demand. As a solution, the insulation for the higher floor could be different from other floors to provide thermal comfort prevent heat loss, and decrease heat design capacity. The most influential factor for the timber wall scenario is the roof for the higher floor. The last floor's roof needs to be appropriately designed which provides thermal comfort for both winter and summer days.

Outputs of the heating analyses show that the shape of the building could be designed by rotating the floors 5 degrees per floor. In this case, the direction of the higher floor would be proper to cope with the wind which acts as a windbreaker. Further, WWR facilitates in reduction of heat loss caused by glazing. As a solution, the side of buildings exposed to wind needs to be designed with a WWR interval of 30-35%. Additionally, considering the results obtained, there is a complex and crucial interaction between embodied CO_2 and building energy efficiency in the early-stage design. However, it is essential to consider and choose proper materials for designing envelopes and facades as well as simultaneously checking out the environmental impacts is required. Finding sustainable replacement instead of chemical insulation would provide acquisitive efficiency for the energy of the building, occupant comfort, and the environment.

Further, results proved that building envelope components, WWR, orientation, and wind direction interact with each other. The window-to-wall ratio in super-insulation walls acts an essential role, as it can provide natural air circulation in a suitable wind direction that is controllable by site orientation. Therefore, the cooling demand will decrease significantly. Furthermore, the findings of the cooling analysis indicate that not every site orientation works for every wall material. For instance, 120 degrees address low cooling demand in curtain walls but not for timber walls. This means that each parameter and material have a significant impact on the building energy efficiency. Additionally, their proper combination during the design phase can increase building energy efficiency and reduce carbon emissions. This study shows that the reason for differences between the results of floors in the reference building is wind exposure, as the design flow rate is the same for floors 4,5,6,7,8 (2 m3/s) and floors 1,2,10 is the same (1.88 m3/s). These results indicate that wind has various impacts on the building envelopes with a height under 10.5 m and middle floors of the building with a height of 10.5-31.5 m (the height of each floor was assumed 3,5 m).

Scenarios within this research address two wall templates in varieties of WWR and orientation of site location. Each wall template in terms of different variables for orientation and WWR is categorized in 18 scenarios (Table 2). According to the findings of the second template scenario, thicker insulation could provide proper efficiency by considering the orientation of the site location. In this study, 15, 30, and 120-degree orientations were addressed to achieve a valid output as the orientation was in the North wind (Poyraz) direction which provides a balance between insulation and strain circumstances. Hence, it is important to notice the WWR which impacts heat transfer and loss remarkably. In this case, cooling energy consumption decreases by 6-7%. The outputs for the template of the third scenario demonstrate that low heating energy demand distinctly results in increasing cooling design capacity. On the other hand, the insulation layers of timber frame walls consider a significant amount of carbon emissions in the building meanwhile increasing heat loss on the last floor and cooling design capacity vastly.

CHAPTER VI

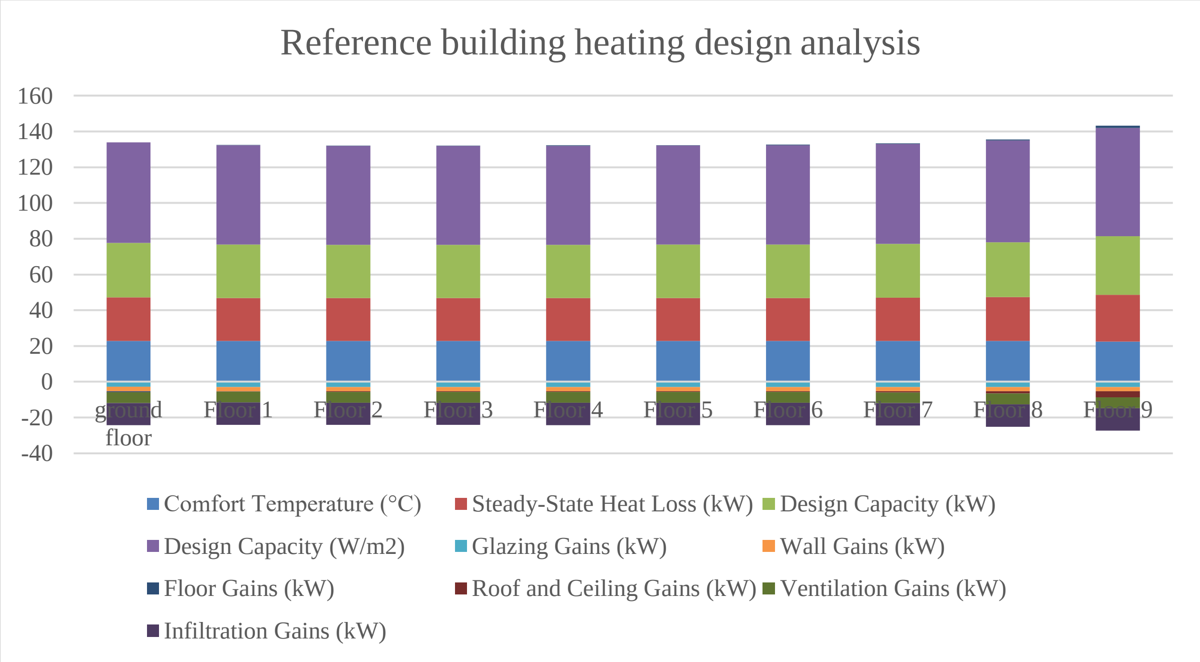
CONTRIBUTIONS AND FUTURE WORK

This research contributes to the AEC literature and industry by providing (1) detailed information about influential factors in heat loss/gain, (2) the factors to achieve energy efficiency and to decrease heating and cooling demand in high-rise buildings, (3) combinations for energy efficient building envelope materials, and (4) knowledge base for an efficient heating ventilation air conditioning (HVAC) system design for high-rise residential buildings. Accordingly, the results would be very useful for assisting professionals in the decision-making process of energy-efficient high-rise residential building design. In addition, this study reveals promising topics in this scope for future research. The findings of this study can be used by policymakers and decision-makers to change existing codes and policies for new high-rise buildings.

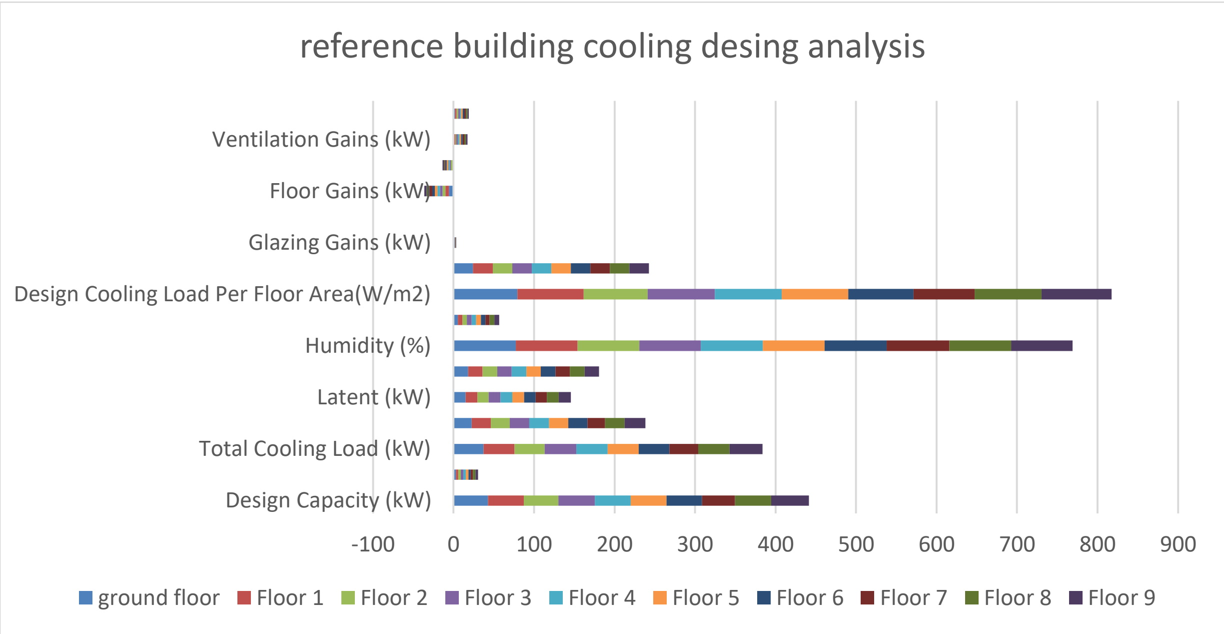
One of the future works for this research could be conducting more case studies in different climate zones. Another future research direction could be comparing the outputs of heating design analysis and cooling design analysis to achieve a more comprehensive result. Another future work could be studying complex shapes for high-rise buildings considering the climate of site locations. Finally, another future study could be addressing natural/less chemical insulation equipment and evaluating their function in the building system. Further, a solution for decreasing the cooling demand while achieving a reduction in heating demand could be different WWR on each side of the building regarding the microclimatic situation. Accordingly, another future research direction could be investigating roof components, roof technologies, and the shape of the building precisely which would provide noteworthy results

APPENDIX A

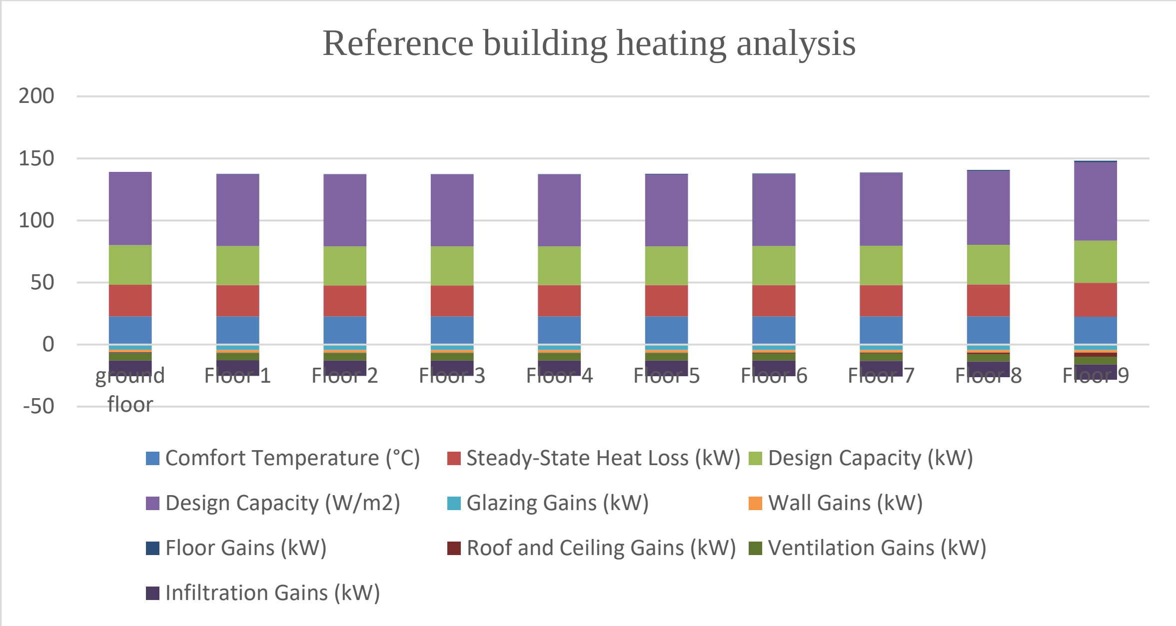
Heating and cooling analyses for each floor.



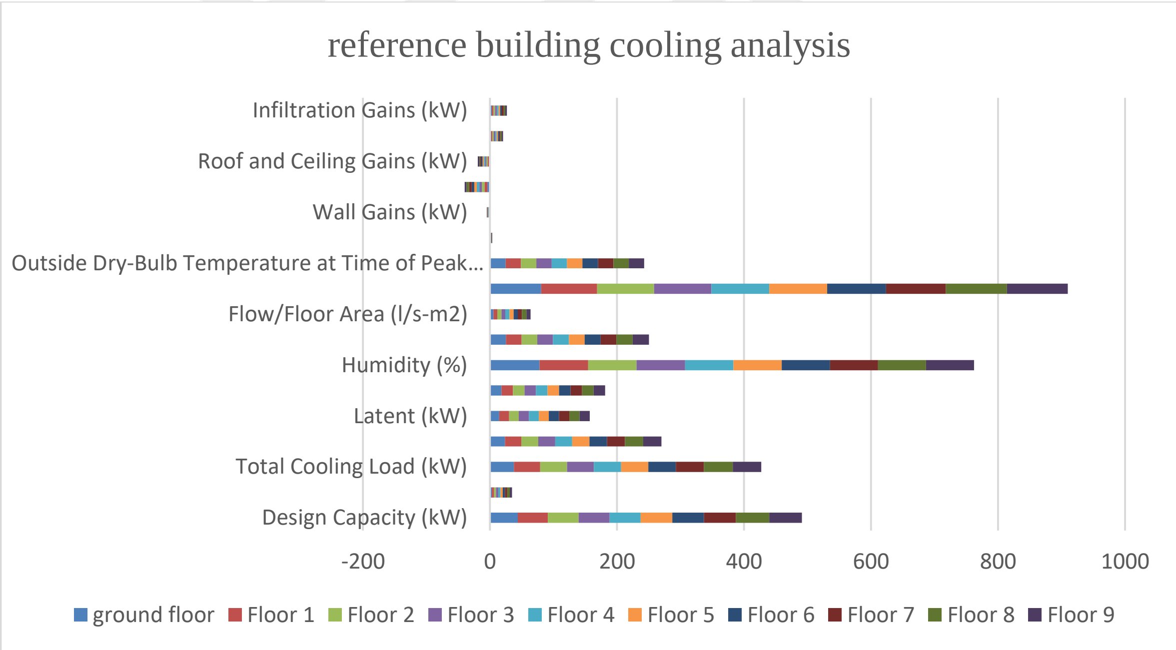
Reference building,0 Orientation, 20 WWR heating analysis result



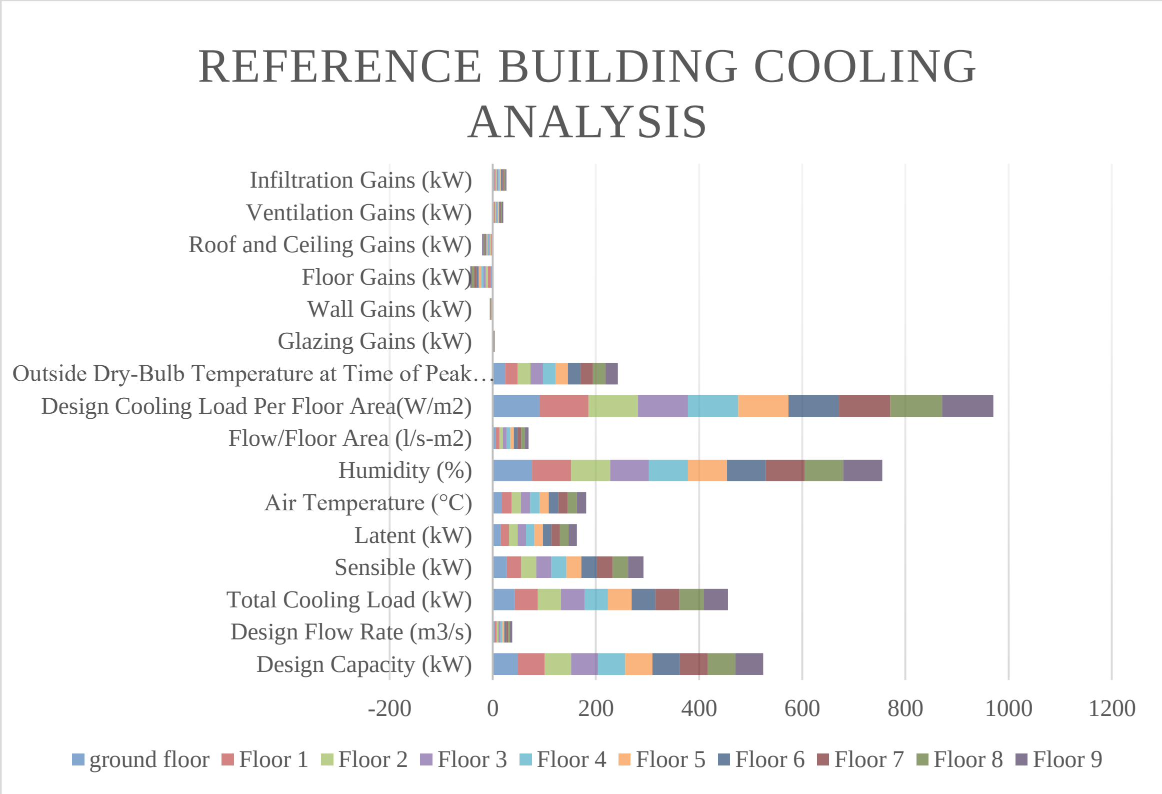
Reference building, 0 Orientation, 20 WWR cooling analysis result



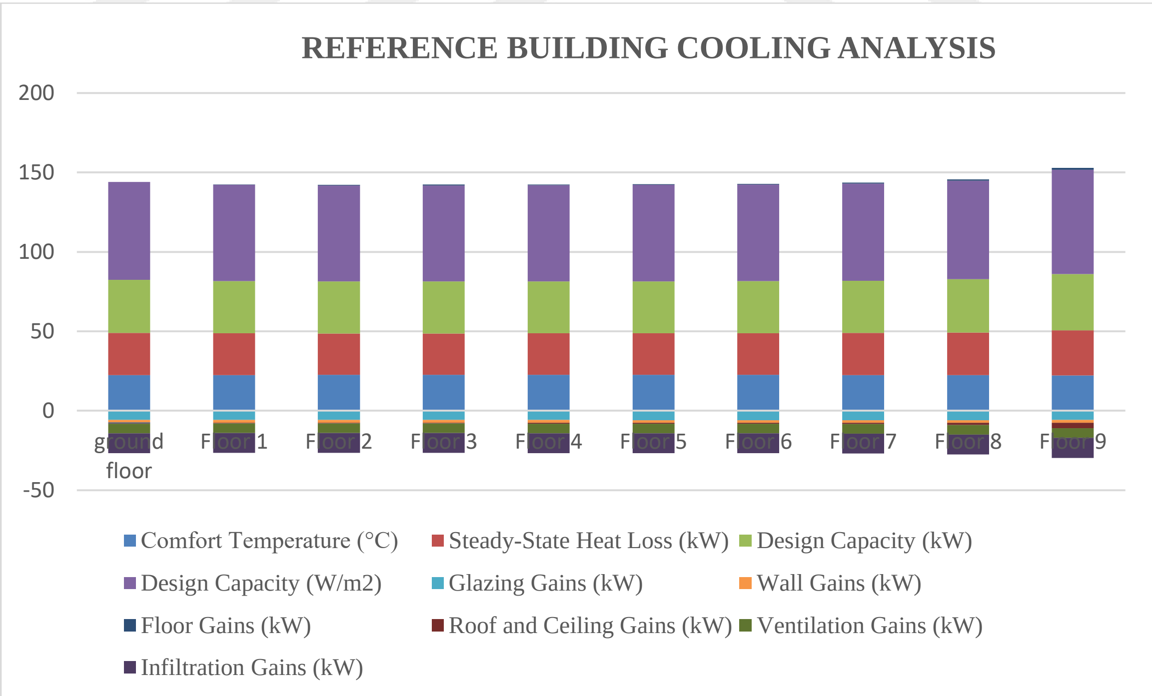
Reference building 0 Orientation, 30 WWR heating analysis result



Reference building, 0 Orientation, 30 WWR cooling analysis result



Reference building, 0 Orientation, 40 WWR cooling analysis result



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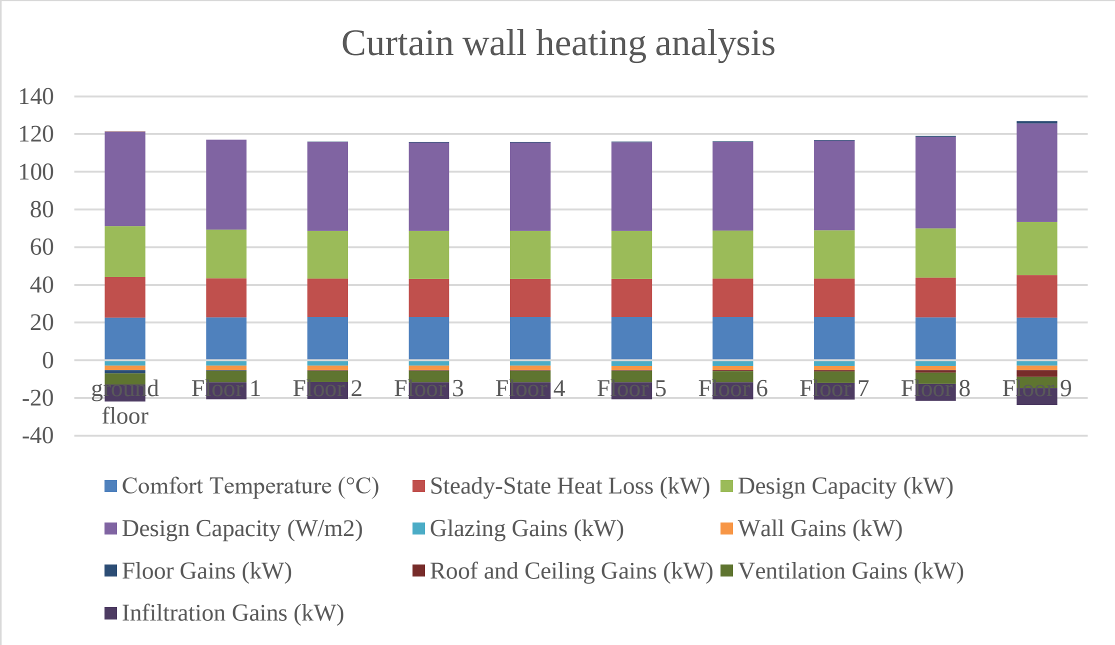
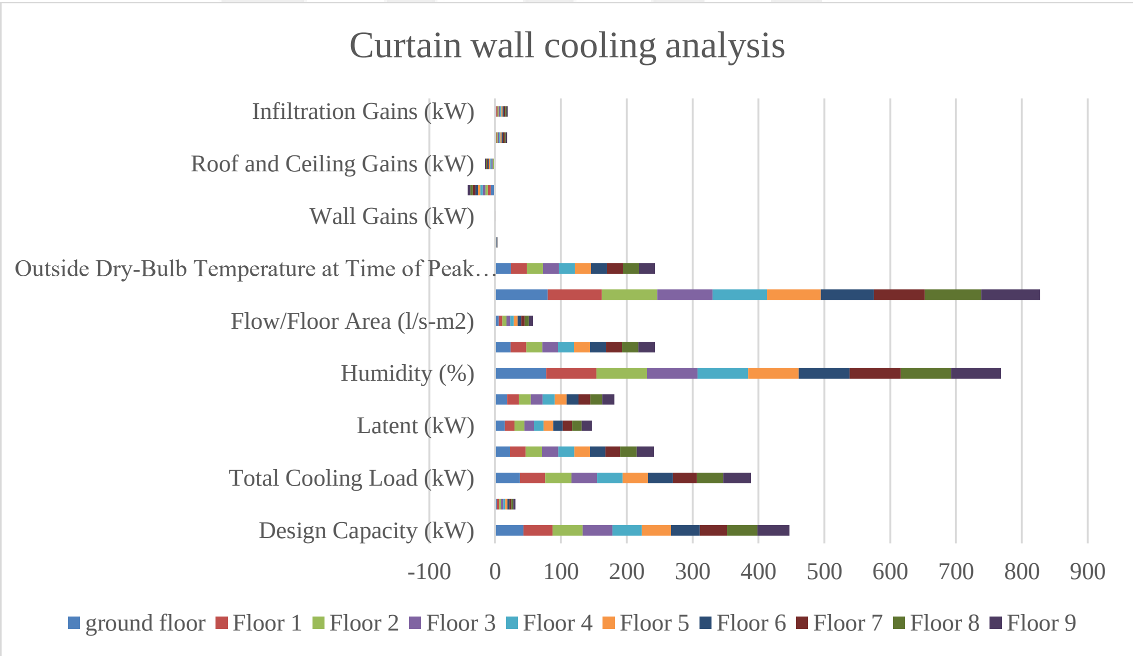


Curtain Wall, 15 Orientation, 20 WWR heating analysis



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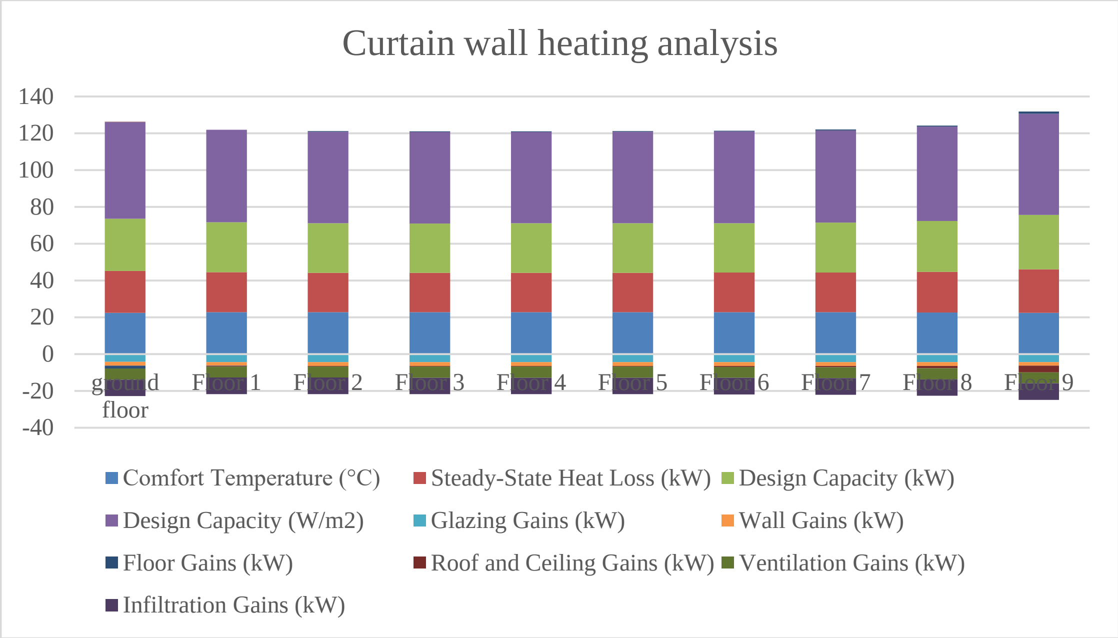
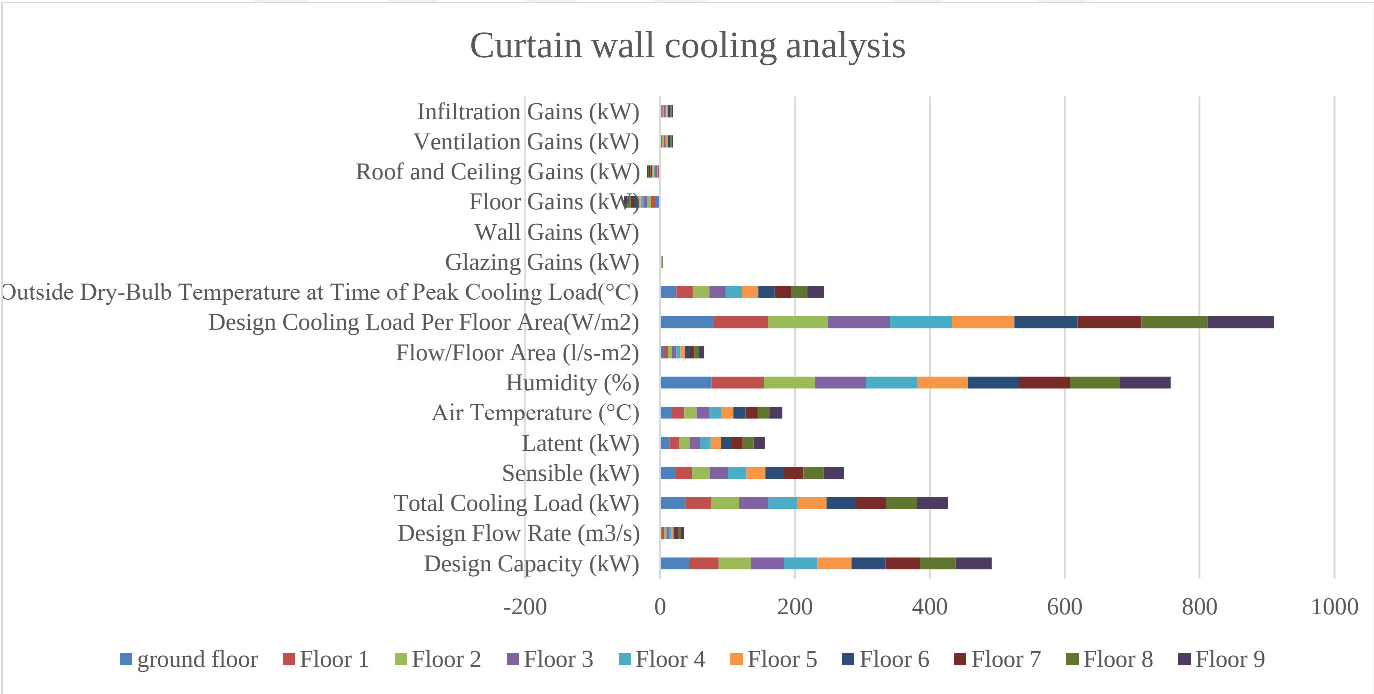
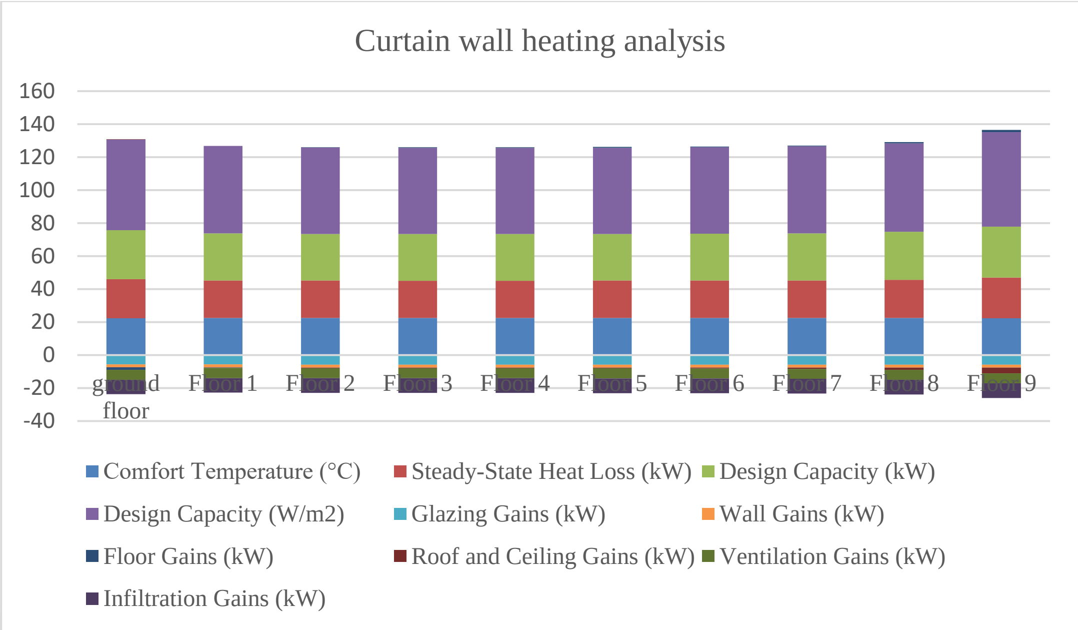


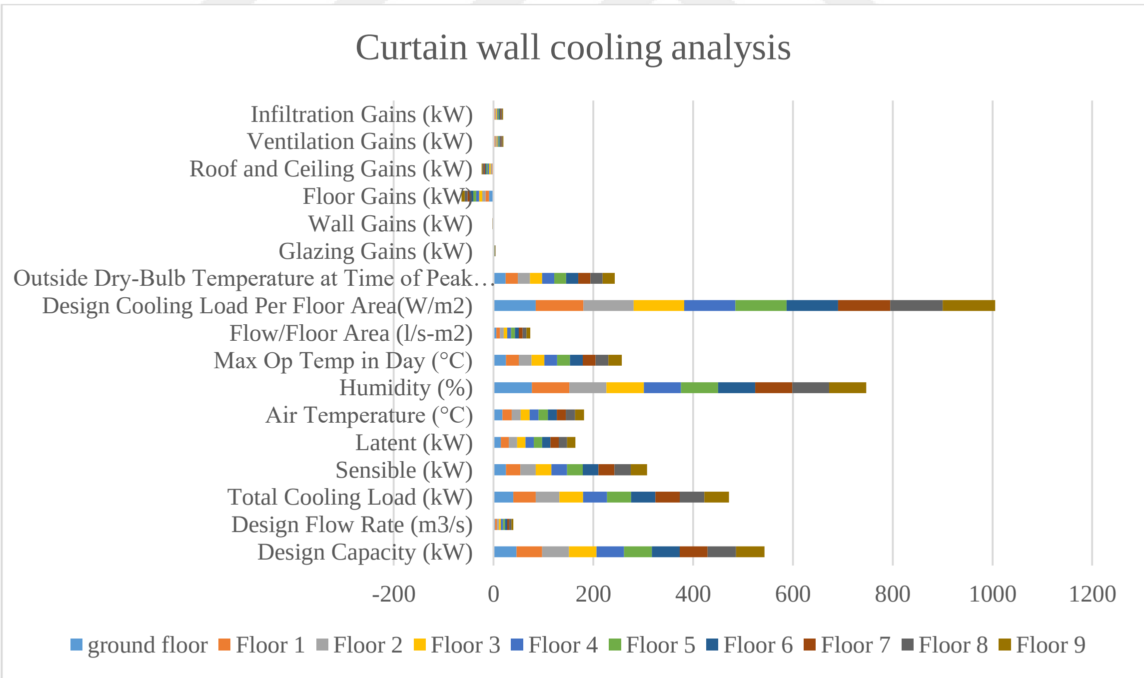
Curtain Wall, 15 Orientation, 30 WWR heating analysis



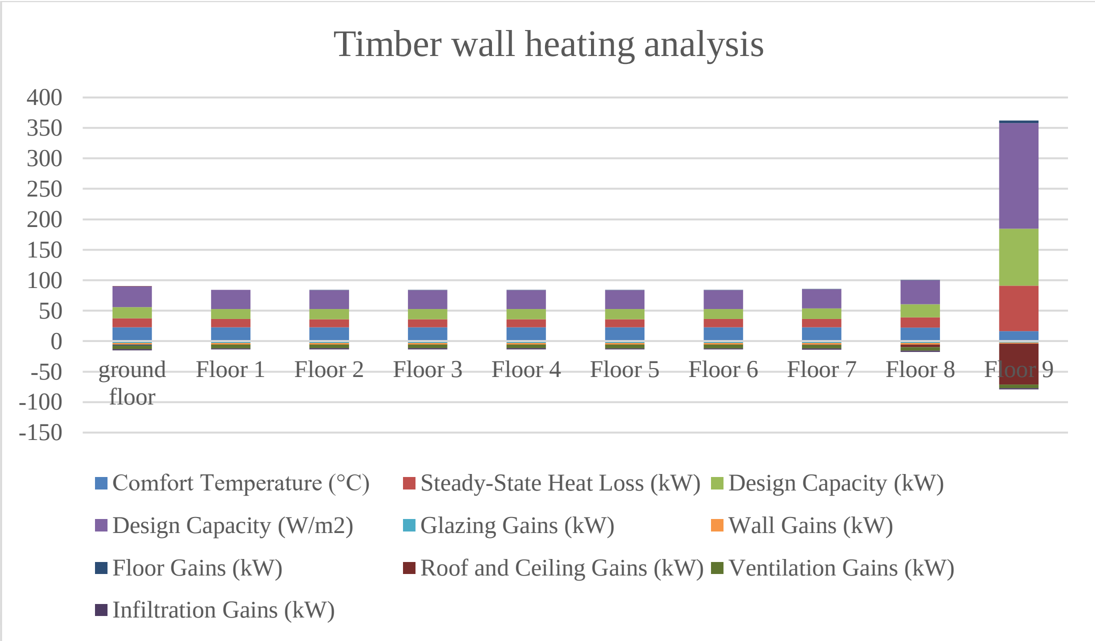
Curtain Wall, 15 Orientation, 30 WWR cooling analysis



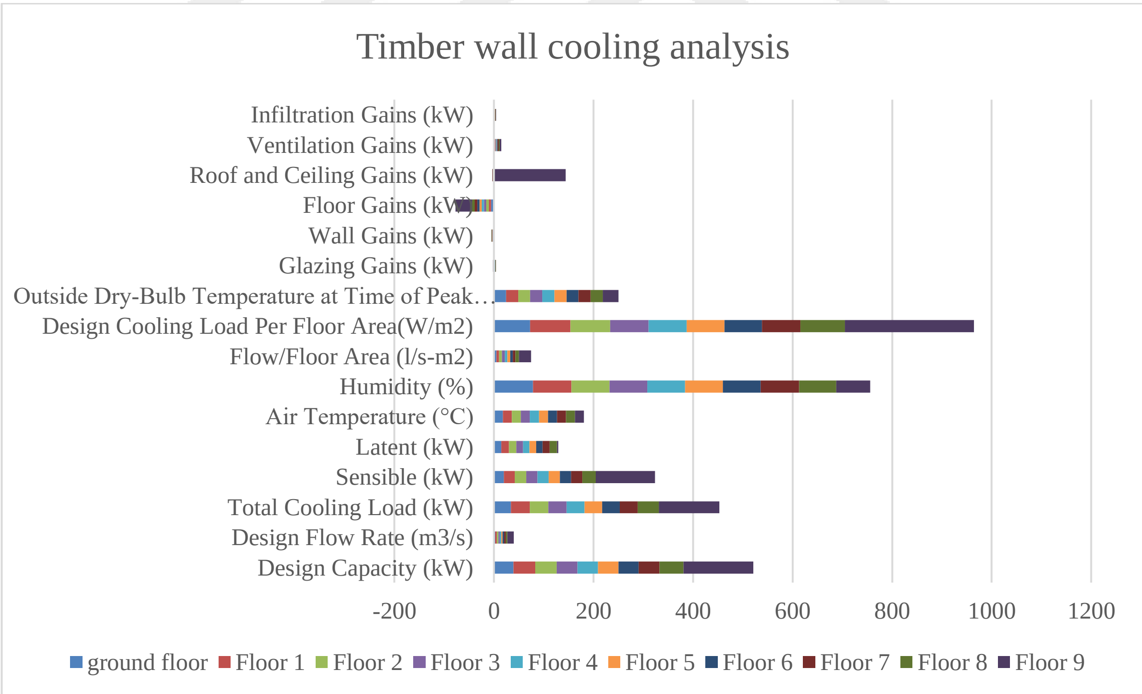
Curtain Wall, 15 Orientation, 40 WWR heating analysis



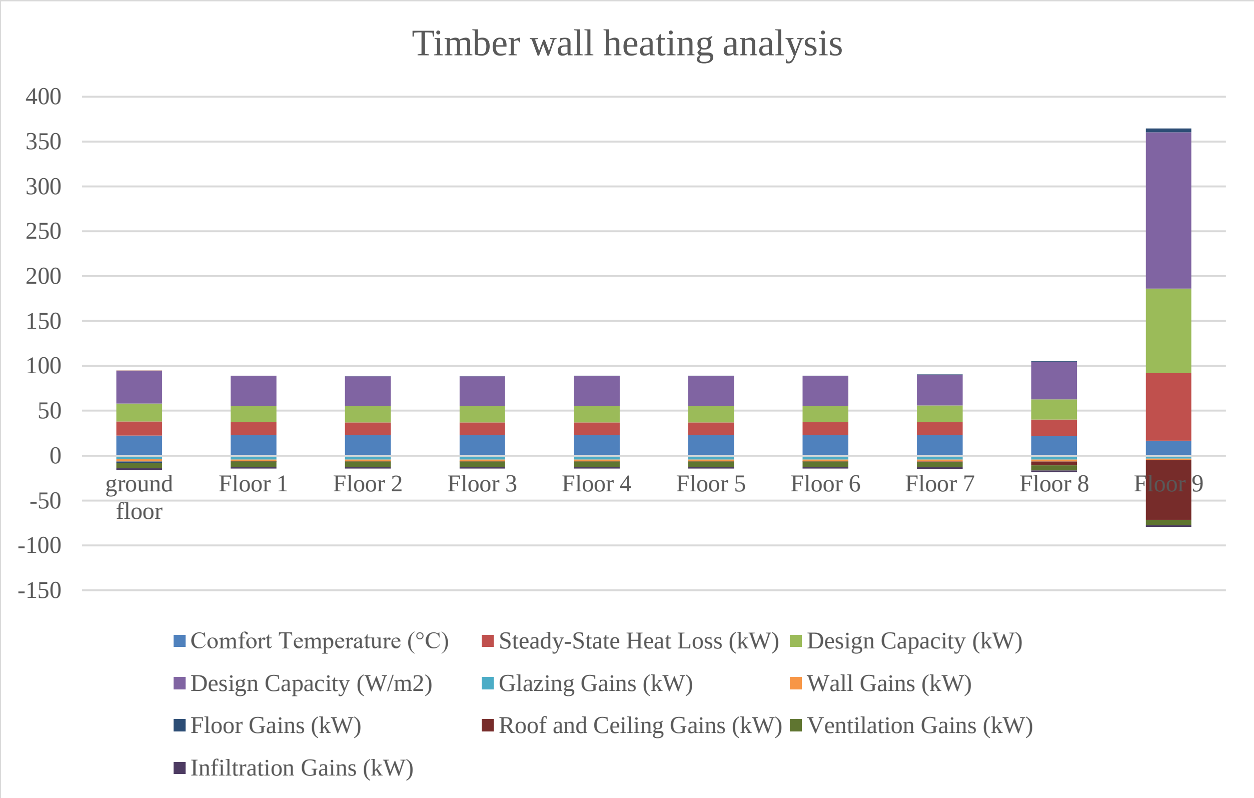
Curtain Wall, 15 Orientation, 40 WWR cooling analysis



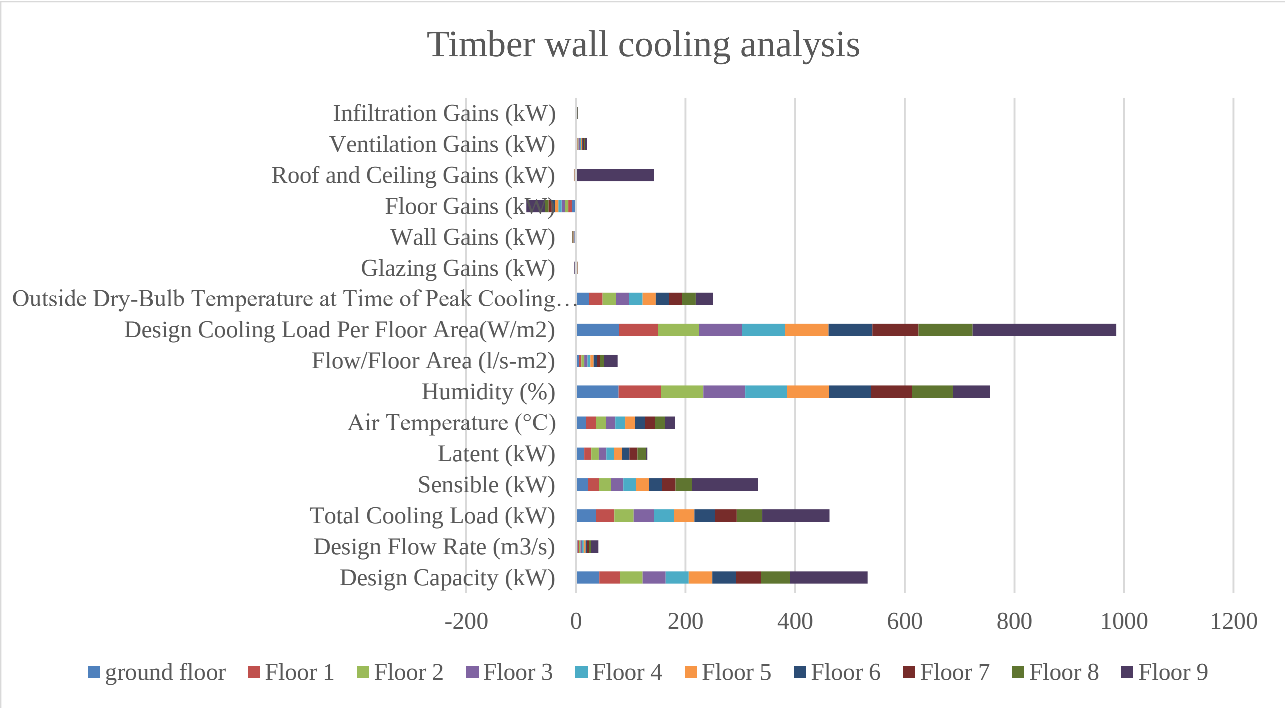
Timber Wall, 15 Orientation, 20 WWR heating analysis



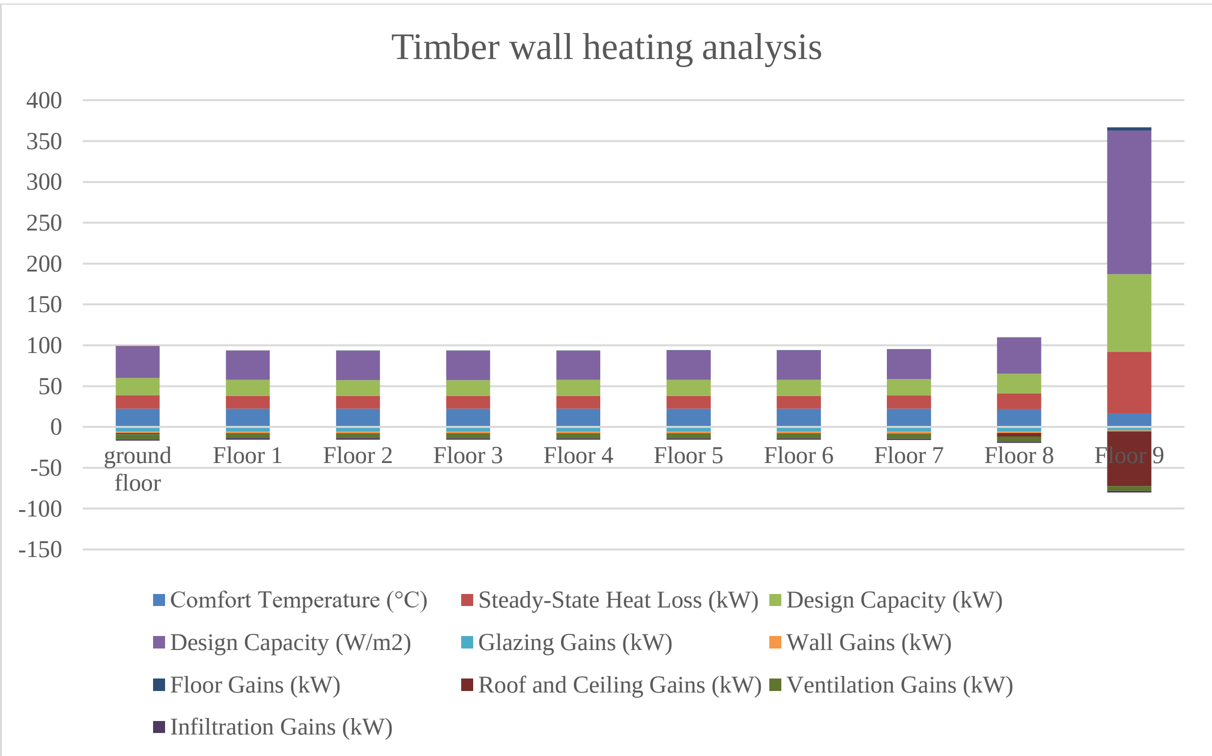
Timber Wall, 15 Orientation, 20 WWR cooling analysis



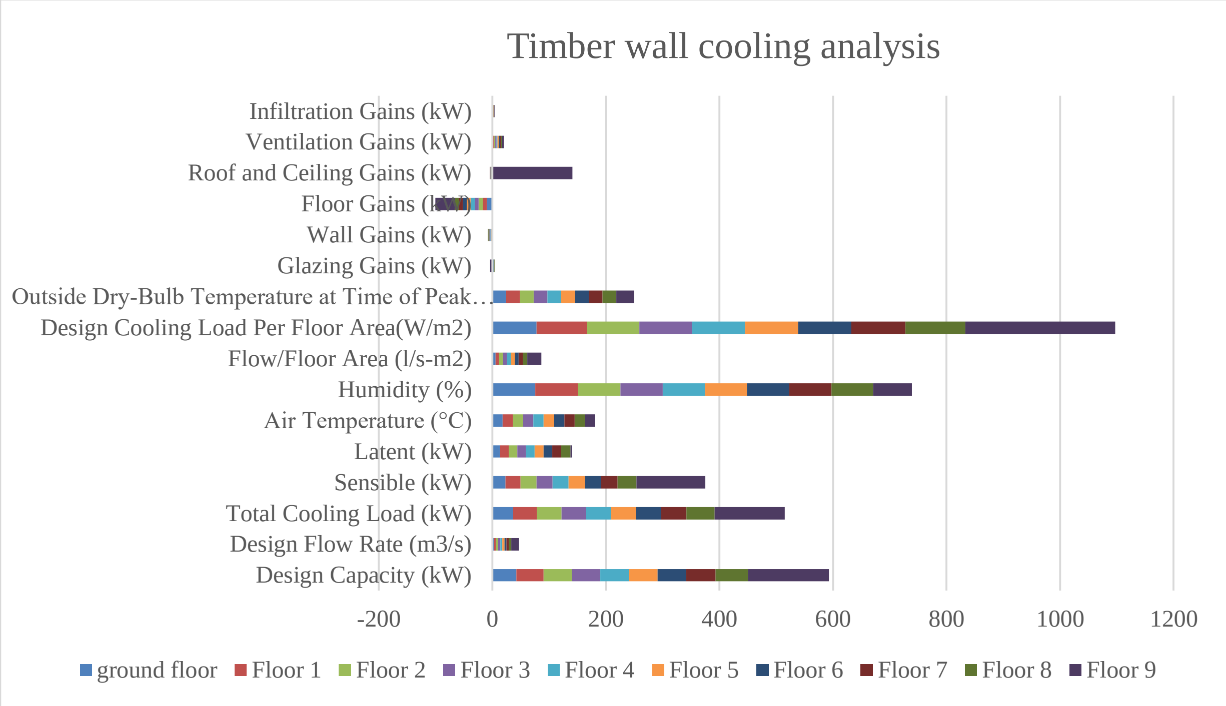
Timber Wall, 15 Orientation, 30 WWR heating analysis



Timber Wall, 15 Orientation, 30 WWR cooling analysis



Timber Wall, 15 Orientation, 40 WWR heating analysis



Timber Wall, 15 Orientation, 40 WWR cooling analysis

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PUBLICATIONS

Within this chapter of the thesis, the previous studies of the researcher which were related to the thesis were addressed for more information as follows;

- Azima, M. and Seyis, S. 2022. "Science mapping the knowledge domain of energy performance research in the AEC industry: A Scientometric Analysis", *Energy* (under review)
- Azima, M. and Seyis, S. 2022. "Designing façade and envelope for a high-rise residential building using energy-efficient materials: A case in Istanbul, Turkey", CIB World Building Conference, Melbourne, Australia
- Azima, M. and Seyis, S. 2022. "Evaluating the impact of building envelope on energy performance: A cooling analysis", *Journal of Construction Engineering Management and Innovation*, 5(1):28-44, 10.31462/jcemi.2022.01028044
- Azima, M. and Seyis, S. 2022. "Comparing the impact of roof components on the energy performance of high-rise residential buildings: Heating Analyses", *The 7th International Project and Construction Management Conference* (abstract accepted, full paper under review).

Science mapping the knowledge domain of energy performance research in the AEC industry: A Scientometric Analysis

Abstract

Plenty of studies on energy performance have been conducted in the last decade; however, none of them considered mapping the scientific research of energy performance in Architecture, Engineering, and Construction (AEC). Such a study may provide a comprehensive understanding of the recent status, hot keywords and topics, and emerging areas of energy performance in the AEC industry and clarify the interaction of influential factors on energy performance. This study aims to reveal the current state of energy performance research in the AEC industry by identifying hot topics and keywords, productive countries and institutions, research gaps, and emerging areas in this domain. For this purpose, systematic bibliometric and scientometric analyses were performed by referring to 5028 bibliometric records published between 2010 and 2022(15th of February). CiteSpace, VOSviewer, and Gephi were used for performing scientometric analysis. According to the results, the USA, Italy, Germany, China, and Hong Kong are the most productive countries. "The University of Berkeley", " Tsinghua University ", " The National University of Singapore ", " Vienna Technology University ", " Eindhoven Technology University ", and " Polytechnic University of Milan " are the most productive institutions. Hot keywords in this subject domain were revealed as 'efficiency ', ' design ', ' performance ', ' simulation ', ' optimization ', ' consumption ', ' model ', ' energy ', and ' thermal comfort '. Emerging keywords in the last five years that had high citation burst were 'policy', 'residential sector', 'performance gap', and 'net-zero energy building'. Document co-citation cluster disclosed the research themes which get

tremendous interest on. In addition, this research presents a knowledge map to provide prominent results. Accordingly, this study contributes to the AEC literature and industry by providing a holistic comprehension of the recent status, hot keywords and topics, and emerging areas of energy performance. This research would be a useful and valuable reference and guideline for the researchers whose research interests address energy performance. The massive volume of data concluded through this research uncovers the gaps in the subject domain. A further research direction could be performing an in-depth study on hot topics and keywords to determine their interaction and development in the scope of AEC literature and industry.

Keywords: Energy efficiency, energy performance, scientometrics, bibliometrics, Gephi, VOSviewer, CiteSpace

Designing façade and envelope for a high-rise residential building using energy-efficient materials: A case in Istanbul, Turkey

Abstract

The construction industry is responsible for 40% of global energy demand as buildings increase heating, cooling, and lighting demand. Therefore, building energy performance has become one of the most significant subjects for the architecture, engineering, and construction (AEC) industry in the last decade. The envelope of a building has an essential role in optimizing energy performance and consumption. The research objective of this study is to analyze and compare the impact of different envelope and façade materials on building energy performance for a high-rise residential building. The research methodology includes a literature review and a case study. The literature review analyzed studies published between 2015 and 2021. In the literary review, 84 publications were extracted from Web of Science and Scopus databases, and the following sources were included: articles published in prominent journals, conference proceedings, thesis, scientific reports, and books. In the case study, passive strategies including building shape, orientation, insulation, window-wall ratio, and shelter were implemented in a 10-story residential building in Istanbul, Turkey. Design-Builder and EnergyPlus were used for analyzing and comparing the energy performance of the different wall, insulation, and glass materials used in the building. Results demonstrate that each parameter and material has a considerable impact on the building energy performance. This study would contribute to the AEC literature and industry by comparing different envelope materials' energy performance and the proper scenario according to Turkey(Istanbul)'s climate. Policy-makers and decision-makers can benefit from the results of this research and

amend the existing codes and policies for new high-rise buildings.

Keywords: Energy performance, envelope, material, High-rise residential building, DesignBuilder, EnergyPlus

Evaluating the impact of building envelope on energy performance: A cooling analysis

Abstract

Buildings require a significant amount of energy for heating, cooling, and lighting. Hence, building energy performance has become one of the most important topics in the architecture, engineering, and construction (AEC) industry in the recent decade. The building envelope plays a critical role in maximizing energy efficiency and decreasing energy consumption generally. The research objective of this study is to examine and compare the effects of three different building envelope types on energy performance in a high-rise residential building. A literature review and case study were performed for achieving the research objective of this study. In the literature review, records (i.e., journal articles, conference proceedings, and scientific reports) published between 2011 and 2021 were included, and Web of Science and Scopus databases were used. In the case study, passive methods including building design, orientation, insulation, window-wall ratio, and shelter were employed for a 10-story reinforced concrete residential building in Istanbul, Turkey. The energy performance of the different wall, insulation, and glass components utilized in the building was analyzed and compared using DesignBuilder software. Findings show that each parameter and material have a significant impact on the energy performance of a structure. This research would make a noteworthy contribution to the AEC literature and industry by analyzing the energy performance of different building envelope types and the appropriate scenarios based on the location. The results of this study can be used by policymakers and decision-makers to revise existing codes and policies for new high-rise buildings.

Keywords: Energy performance, energy efficiency, envelope, high-rise residential building, cooling analysis, DesignBuilder

Comparing the impact of roof components on the energy performance of high-rise residential buildings: Heating Analyses

Abstract

Regarding UN Environment Program 2020 global status report for building and construction, residential buildings contribute 22% of energy demand, 11% of indirect carbon emissions, and 6% of direct carbon emissions. Energy performance has gained notice significantly in the architecture, engineering, and construction (AEC) industry to both decrease building energy consumption and achieve sustainability goals simultaneously. Especially, roof components cause heat losses of 18%. However, previous studies did not consider heat gain/loss of roofs. Hence, materials and implementation techniques of roofs in buildings have an essential impact on building energy performance. The goal of the research is to perform heating analyses for evaluating and comparing the impact of different roof materials (i.e., metal, asphalt, concrete, slate, and wood) and insulation materials (i.e., polyurethane spray foam, rigid insulation board, batt insulation, loose-fill, and structural insulated panels) on the energy performance of high-rise residential buildings. The research methodology includes a literature review and case study. In the literature review, studies published between 1973 and 2022 were examined using Web of Science and Scopus databases. Several sources (i.e., journal articles, conference proceedings, scientific reports, and books) were included within the scope of this study. In the case study, a 10-story residential building was designed utilizing passive techniques (e.g., PV panel roofs, cool roofs, and green roofs). DesignBuilder software was used for comparing the heat loss/gain of various roof and insulation materials. This study contributes to the AEC literature and industry by performing a comparative analysis of the impact of various roof and insulation materials on the energy performance of high-rise residential buildings. The findings could help practitioners and academics to comprehend the impact of various roofing and insulation materials on building energy performance.

Keywords: Energy performance, heating analysis, roof, material, High-rise building, DesignBuilder