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A model for designing climate adaptive shading devices: the case of Bayrakli Tower

İklime uyarlı gölgeleme elemanları tasarımı için bir model: Bayraklı Tower örneği

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A Model for Designing Climate Adaptive Shading Devices: The Case of Bayrakli Tower

Highlights

- *Simulation model is validated.*
- *Shading device requirements are analysed.*
- *Climate adaptive shading device proposal is developed.*
- *Simulation results are compared and discussed.*

Graphical Abstract

This study is expected to examine the effects of Climate Adaptive Shading Devices (CASD) on building energy performance through the outputs derived from simulation results of an existing building.

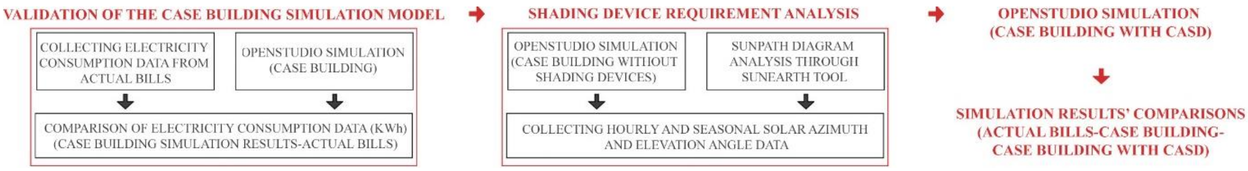

Figure. Methodology

Aim

This study aims to examine the energy performance of the case building and to propose a methodology for implementing CASD.

Design & Methodology

Sun-path diagram analysis and Openstudio simulation tool are used for developing and evaluating the effects of CASD on building energy performance.

Originality

This study is significant in literature by examining the effects of the developed CASD on the energy performance of an existing building through simulation.

Findings

Even CASD increase heating load, they have a positive effect on energy performance of a building by helping with overheating problem.

Conclusion

This study reveals a solution for the overheating problems of the case building by proposing Climate adaptive shading devices (CASD).

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

İklime Uyarlı Gölgeleme Elemanları Tasarımı İçin Bir Model: Bayraklı Tower Örneği

Araştırma Makalesi / Research Article

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ÖZ

Bir yapının enerji performansı üzerinde belirleyici bir bileşen olan cephe; iç ve dış şartlar arasındaki sınırı oluşturmaktadır. Bu sebeple, mevcut bir ofis yapısı; soğutma enerjisi tüketimi düşürülerek bina enerji performansını geliştirmek için cephesine entegre edilmiş olan güneş kırıcı elemanlar üzerinden çalışılmıştır. Isıtma ve soğutma için tüketilen elektrik enerjisi hesabı OpenStudio simülasyon yazılımı aracılığıyla yapılmıştır. Çalışılan binanın simülasyon modeli, elde edilen simülasyon sonuçlarının aylık elektrik faturalarıyla karşılaştırılması yoluyla doğrulanmıştır. Gölgeleme elemanı ihtiyaçlarına karar vermek için, çalışılan binanın gölgeleme elemanı olmadan simülasyonu alınıp sonuçlar Güneş diyagramı analizi sonuçlarıyla birlikte çalışılmıştır. Güneş kırıcılar 'geçirgenlik özelliği' ve 'yükselme açısı' değişkenleri özelinde, güneşin saatlik ve mevsimsel hareketlerine bağlı olarak çalışılmıştır. Sonrasında, toplanan bilgiler uyarlı gölgeleme elemanlarının karakterini oluşturmak amacıyla kullanılmıştır. Sonuç olarak; mevcut gölgeleme elemanları ve önerilen uyarlı gölgeleme elemanları, elektrik tüketimleri ve pencerelerin güneş radyasyonu kaynaklı enerji kazanımı değişkenlerine dayalı olarak karşılaştırılmış ve tartışılmıştır. Öneriler arasından, Güneşin hem saatlik hem de mevsimsel hareketlerine uyarlılık gösteren gölgeleme elemanları, soğutma enerjisi tüketimini düşürmek adına en fazla gelişme gösteren sonuçları vermiştir. Ayrıca, ileriki çalışmalarda en iyi performansı sağlayan cephenin geliştirilebilmesi için öneriler verilmiştir.

Anahtar Kelimeler: Bina enerji performansı, openstudio simulasyonu, güneş yörüngesi diyagramı, iklime uyarlı gölgeleme elemanı, elektrik tüketimi.

A Model for Designing Climate Adaptive Shading Devices: The Case of Bayrakli Tower

ABSTRACT

Façade is accepted as a determinant component on energy performance of a building, forming the boundaries between inner and outer conditions. With an intention to improve the building energy performance of an existing office building, façade integrated shading devices are examined through the cooling energy consumptions. OpenStudio simulation software is used for calculating heating and cooling electricity consumptions Shading. The ilding simulation model is validated by comparing the simulation results with monthly electricity consumption bills. device requirements are determined by using the building model without shading devices and simulation results are studied together with the sun path diagram analysis results. Hourly and seasonal solar movements are considered as the main parameters affecting the 'transparency' and 'elevation angles' of the shading devices. As a result of the shading device requirement analysis, climate adaptive shading device (CASD) scenarios are presented for the case building. Consequently, existing shading devices and proposed CASD scenarios are compared and discussed in terms of electricity consumptions and window solar radiation energy parameters. As a result of the comparisons, shading devices that are adaptable to both hourly and seasonal solar movements gave the highest improvement results in terms of decreasing cooling energy consumptions. Also, suggestions are given for developing the best performing façade for further studies.

Keywords: Building energy performance, openstudio simulation, sun-path diagram, climate adaptive shading device, electricity consumption.

1. INTRODUCTION

Construction sector has been following the global 'energy efficient' movement regarding to the obvious constraints on the natural environment created by the built environment. National and International regulations, codes and directives have been the major push for the implementation of new policies in the sector.

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Following the global steps, Turkey has built up a series of regulations starting from 2008.

However, implementation part of the sector shows a strong resistance by keeping the regulations as 'requirements' to fulfil, not as an attitude to embrace.

Since 60% of buildings' energy consumption is caused by heating, cooling and hot water needs; energy efficiency approaches should be mainly focused on these issues. In this case, optimizing the building envelope as a significant factor on buildings' heating and cooling energy demand would help for minimizing the total energy loads. According to the Organization for Economic Co-operation and Development [1]; a building with a high-performance envelope in a cold climate consumes the 20-30% of a standard building's heating load. Indeed, the cooling load gain in a hot climate is also changing between 10-40%.

This study deals with energy performance of an existing high- rise office building in İzmir. Bayraklı Tower is chosen as the case building of this research to study on its heating and cooling energy consumptions; focused on shading devices integrated to the façade. Occupants of the south facing offices have cooling demand both in summer and winter seasons. Even though shading devices are densely placed on the southern façade, curtain wall façade causes over- heating problems.

The paper aims to present a methodology for improving the energy performance of an existing office building in İzmir by proposing climate adaptive shading devices (CASD). Different methodologies are combined on various components and processes to constitute the steps of the main aim of this study by: Establishing the shading device requirements of the building, proposing CASD for the building and presenting the most efficient proposal for improving building energy performance by decreasing cooling energy consumption. This study considers; energy consumption of heating, cooling and fan usages as the energy performance indicators, while hourly and seasonal solar movements are accepted as the outer factors on the adaptivity behaviour of the façade components.

Presented methodology can be used for developing CASD proposals through a solar diagram analysis tool (Sunearth Tool web-based software) and CASD proposals can be compared over their effects on building energy performance of a building by using a simulation tool (OpenStudio simulation software). So that energy performance of a building can be improved by using CASD. Although the methodology is assigned to an existing case building in this study, it can be used regardless of the case building (such as new constructions, different building typologies, other climate conditions etc.)

2. LITERATURE REVIEW

According to the OECD data, compared to a standard building envelope is decreasing the heating loads 20-30% in a cold climate and 10-40% of the cooling loads in a hot climate [1]. As building envelope is a key component for reaching a better energy efficiency target, the path of 'climate adaptive façade' concept is followed for increasing building energy performance. For maximizing the energy savings in buildings while providing the needed indoor environmental comfort, energy and mass flow can be managed and modulated by 'Adaptive' or 'Responsive Building Elements (RBE)' or systems [24]. According to a completed project of the International Energy Agency—Energy Conservation in Buildings and Community Systems Programme (IEA-ECBCS), responsive building elements should be developed, applied and implemented for improving the energy efficiency in the built environment. Mainly designed as construction elements, Responsive Building Elements can transfer and store heat, light, water and air actively. IEA–ECBCS Annex 44 indicates that building envelopes has the largest potential to minimize the energy use in buildings by integrating adaptive technologies [25].

By means of the 'exclusive' approach; a well-insulated and air tight building envelope can be accepted as a 'static' barrier creating a boundary between inside and outside. Following a 'selective' building envelope understanding, heat and mass flow can be adjustable by using adaptive or responsive building elements [8]. Although the daily and yearly changing meteorological conditions affect the occupancy and comfort needs, the conventional building shells are mainly static and don't respond to these changes [26]. But a climate adaptive building shell (CABS) can adapt itself according to the changing climatic conditions while providing the occupant needs and saving energy [13]. CABS can repeatedly and reversibly change its functions, features or behaviours over time in response to changing performance requirements and variable boundary conditions. This helps to improve the overall building performance in terms of primary energy consumption and provides the needed thermal and visual comfort conditions.' [27]

Since the word 'adaptive' refers to the changeable, mutable, flexible, instable features; 'Adaptability' is defined as 'the ability of a system to deliver intended functionality considering multiple criteria under variable conditions through the design variables changing their physical values over time' [28]. The words 'active, advanced, dynamic, intelligent, interactive, kinetic, responsive, smart, switchable are also used corresponding to the word 'adaptive' [26]. The adaptive behaviour according to the changing environmental conditions in time is not a new concept in architecture; even an operable window on a façade and a curtain are both conventional adaptive solutions [29]. The first 'adaptive façade' known in literature, was designed by Jean Nouvel for the Institut du Monde Arabe; built between the years 1981-1987 in Paris [7]. 'Climate Adaptive Façades' can be defined as the façade solutions that can adapt themselves to the inner and outer factors manually, mechanically or by the behaviour of smart materials used.

Considering the data achieved by shading device requirement analysis; we can say that shading device requirements of a façade changes during a day parallel to the changing solar azimuth and elevation angles. To understand when shading is needed for a façade; solar azimuth angles are studied on hourly base for each façade orientation and existing shading devices are positioned with proper elevation angles to have a better performing façade for the case building. Since the word 'adaptive' refers to the changeable, mutable, flexible, instable features; 'Adaptability' is defined as 'the ability of a system to deliver intended functionality considering multiple criteria under variable conditions through the design variables changing their physical values over time' [30]; this study approaches 'adaptability' in relation with the position and material transmittance of shading devices.

Since the structure of this paper is founded on 'building energy performance calculation'; literature review is made on building energy performance directive and regulations of European Union and Turkey. Then building energy performance is reviewed in relation with climate adaptive façades, by focusing on the significant publications in the field.

As a major concept of this study, 'building energy performance' was added to literature by European Commission with Energy Performance of Buildings Directive (EPBD), published in 2002. The directive is presenting the definition and methodology of the concept in a clear framework which has been developing with new targets and policies based on the initial methodology. The main requirements of the directive are stated as; the minimum energy performance demands should be provided; the national methodologies should be provided to calculate and certify the energy performance of the building. Energy performance of a building is defined as the calculated or measured amount of energy demand associated with a typical use of the building, which includes, inter alia, energy used for heating, cooling, ventilation, hot water and lighting. Building energy performance calculation methodology is also described by using thermal characteristics and other factors that play an increasingly important role are added; such as heating and air-conditioning installations, application of energy from renewable sources, passive heating and cooling elements, shading, indoor air-quality, adequate natural light and design of the building. [2]

The attempt of Turkey in developing policies for 'building energy performance' has been proceeding since the publication of 'Code for Energy Efficiency' in 2007; followed by many regulations and national building energy performance assessment tool 'Bep-TR'. The energy performance of the buildings is calculated by a simple hourly dynamic method based on Turkish Standard TS 825. [3] TS 825 was first published on 22nd of May 2008 with the title of 'Thermal Insulation Requirements for Buildings', focusing on 'the net heating energy demand calculation rules' and 'the maximum heating energy usage limitations'. [4] According to the data collected on January 2017; 485,000 buildings had been certified through BEP-TR assessment tool and that means 94% of the new constructions' and 6% of the existing buildings' energy performance had been examined. With the status at large in Turkey; 73% of these buildings were improved to a 20-40% higher energy performance level; and 26% of these buildings were improved to a 40-60% higher energy performance level. However, 90% of these certified buildings reached to higher energy performance levels by heat insulation applications.

As a term, 'climate adaptive façade' refers to a wide context in literature including either a conventional curtain or a photovoltaic shading device working with solar receptors. Even the referred meaning is not new, it is new as a concept studied by a limited group of people through case studies, mainly focusing on the definition and classification in literature:

Van Dijk (2010) made a research on possibilities of adaptation in the façade of the future faculty of Architecture at TU Delft. The climate adaptive façade is shown as a good way of contributing good comfort levels of a building for its users and the surroundings [5]. Loonen (2010), published a booklet on the overview of 100 CABS including case studies, prototypes and research projects that can be used as a guide by researches and designers to follow the adaptive building shell technology [6]. Loonen et al. (2011) explores and quantifies the latent potential of CABS by using building performance simulation in combination with multi-objective optimization and advanced control strategies. The main approach of the study is to provide a guidance to the simulation tool users by changing the question of the simulation mentality from 'what if' to become 'how to' [7]. Loonen et al. (2013) published a comprehensive literature review on classification of Climate Adaptive Building Shells (CABS). Dynamic exterior shading systems are mentioned as more applicable in cost-effectiveness manner and pointed out as a smooth transition towards widespread application of more advanced CABS [8]. Loonen et al. (2015) made a research with the aim of classifying climate adaptive façade concepts and presented an analysis of existing classification approaches to identify requirements and challenges of these processes [9]. Attia et al. (2015) made a review on current state of the art of assessment strategies for adaptive façades and found out that in literature there is no focus on this field [10]. Aelenei et al. (2016) studied on analysis of existing concepts and case studies of climate adaptive façades to propose a new approach for characterization of these façade elements which are pointed as primary objectives of improving energy performance of buildings and human's comfort [11]. Loonen et al. (2017) published a review article on the definition of unique requirements for successful modelling and simulation of adaptive façades; review on the capabilities of five widely used BPS tools and discussion on various ongoing trends and research needs [12].

In general, climate adaptive façades are assessed through their effects on the energy performance of hypothetical buildings, so the results can not be compared with real data. Current studies covering the context of this paper are given in a chronological order as follows:

Loonen et al. (2010) studied on exploring the role of 'Building Performance Simulation (BPS)' in Climate

Adaptive Building Shells (CABS) through a case study; asserting that BPS is confirmed to be a valuable tool for designing buildings with CABS and proved as an active tool in product design and development [13]. Kim and Jarrett (2011), aimed to determine the influence of a climate adaptive façade system on the energy performance of a hypothetical office building located in a cold climate. Since the heating loads decreased compared to a baseline façade system; the future target is given as, verifying the simulated energy performance data by testing the adaptive façade system experimentally [14]. Abboushi (2013) presented a master thesis on developing high performance office buildings façades by using adaptive shading and the selective reflector light shelf technologies [15]. Bianco et al. (2017) focused on the solution of high energy demand and discomfort conditions in buildings with large transparent façades. They proposed a new dynamic shading device based on the integration of phase change materials (PCM) in an alveolar polycarbonate panel and presented the findings [16].

In literature, climate adaptive façades are pointed out as a potential field for improving building energy performance. Compared to the advanced climate adaptive façades, dynamic shading devices are pointed out as a smooth transition by being more feasible to apply considering the cost effectiveness.

Regulations are showing computer aided simulation as a tool for calculating building energy performance, by giving the answer to the question 'how to'. However, it has been a matter of discussion to use the same simulation tools for assessing effects of climate adaptive façades on building energy performance. In the field of climate adaptive façades, simulation is considered as a tool which is giving the answers to the question 'how to'; that would serve as a guide in design and development processes.

Considering the significant points in literature review; for improving the energy performance of an existing building climate adaptive shading devices are proposed by using a simulation tool as a design guide and the presented methodology is added to literature for future studies.

3. INTRODUCTION AND SIMULATION OF THE CASE BUILDING

Pointed out in literature review, studies are mainly on hypothetical case buildings and the results can not be compared with real data. This study fills the gap at this point by comparing simulation results with the real data and therefore can calculate the most accurate simulation results of CASD. So this study deals with improving the energy performance of an existing building by proposing a climate adaptive façade with the most accurate simulation results. As remarked by the literature review, the chosen simulation tool 'OpenStudio' is used as a guide to find out the answers to the question of 'how to apply CASD?'. OpenStudio can supply realistic output data about the energy performance of a building by using detailed dynamic calculation methodology of EnergyPlus software integrated into SketchUp 3D modelling environment. In fact, using a dynamic method is recommended by European Commission to reach reliable results [17].

Case building: Bayraklı Tower is located in İzmir (latitude: 38.4511138, longitude: 27.1876025), Western Turkey. The building has 37000 m^2 closed area; with 23 stories of mainly offices and sports hall, ground floor with a shopping mall and 3 basements with car park. All the details of the building are taken from architectural and mechanical application projects. The real and simulation model views of Bayraklı Tower from the south-east orientation is given in Figure 1a and Figure 1b.

Since the study is mainly dealing with façade of the case building, exterior surface constructions are defined in detail for non-transparent and transparent elements in Table 1 and Table 2. Non- transparent façade layers are the outer surfaces of the beams.

Table 1. Non-transparent façade surfaces

Materials	Thickness (m)	Conductivity (W/mK)	Density (kg/m3)	Specific Heat (J/kgK)	Thermal Absorptance (emittance)	Solar Absorptance	Visible Absorptance
Tempered glass	0.008	1.4	0.1	0	0.2	0.73	0.021
Air gap	0.02						
Tempered glass	0.006						
Air gap	0.04	0.03	1225	0	0.9	0.7	0.7
Fireproof gypsum board	0.012	0.16	800	90	0.9	0.7	0.7
Heat insulation (rockwool)	0.08	0.05	19	960	0.9	0.7	0.7

Table 2. Transparent façade surfaces

Material	Thickness (m)	U-factor (W/m^{2}K)	Solar Heat Gain Coefficient	Visible Transmittance
Temperated glass	0.008	1.4	0.20	0.16
Air gap	0.014			
Interior glass	0.006			
PVB	0.00076			
Laminated glass	0.006			

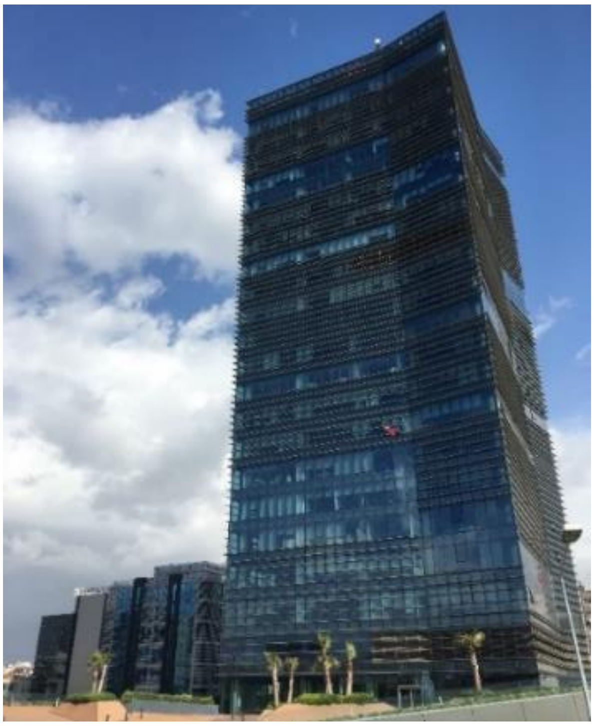

Figure 1a. Bayraklı Tower (Hande Odaman Kaya, 2016)

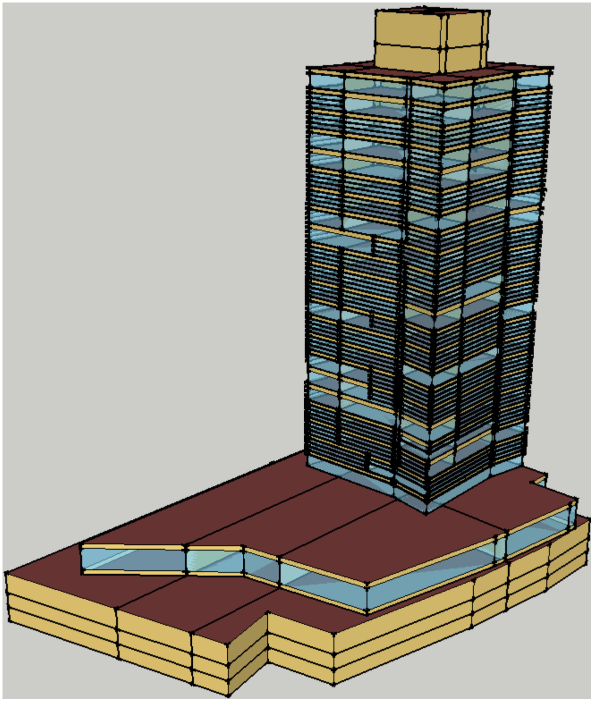

Figure 1b. Bayraklı Tower 3D model

Figure 2 is presenting a detail drawing of the existing shading devices located with 90° elevation angle. Physical features of the devices are same in all orientations and they are located 95 cm distant to each other along 380 cm height of the floor. Shading devices are placed with a layout considering the façade orientations, for instance northern façade is significantly less shaded where shading devices has a density on southern façade.

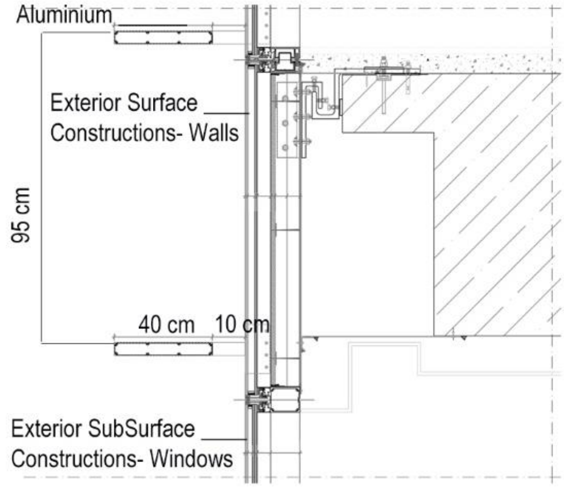

Figure 2. Façade detail

After the building model is constructed with architectural details, mechanical projects are studied and transferred to the model in OpenStudio. Case building is defined by vertical thermal zones which are conditioned by variable refrigerant flow (VRF) systems installed in the technical spaces on 2nd and 14th floors. There are 52 thermal zones with 93 VRF outdoor systems and 506 indoor terminal units. As it is intended to discuss about the effect of façade on the energy consumptions; the parameters that are not available for the case building are defined by using OpenStudio templates referring to ASHRAE. Lighting, electric equipment and occupancy loads of the defined spaces are given in **Hata! Başvuru kaynağı bulunamadı.** 3 [18].

The loads given in Table 3 are the overall values for the spaces which has variable occupancy rates depending on days of the week and hours of the days. These variables are given as fractions from 0 to 1 in **Hata! Başvuru kaynağı bulunamadı.**4 for daily and hourly schedules; defining the valid rates of the loads for the time periods. Also, VRF availability schedule is integrated to **Hata! Başvuru kaynağı bulunamadı.**4 to present the time-based working principle of the heating and cooling systems.

In **Hata! Başvuru kaynağı bulunamadı.**5, heating and cooling setpoint schedules of a 'Large Office Building' are presented in Celsius degrees (°C). Time slot for the study is defined by means of seasons, days and hours. Seasons are dated according to vernal and autumnal equinoxes. Days of a week are also considered as working days or holidays and days are also split into hours [18].

After entire building is modelled by the software, simulation is carried out for the year of 2015. The weather data (.epw file) collected from İzmir, Güzelyalı for the period of record 2008-2017. [19]. As the study is mainly based on simulation calculations, it is essential to verify the accuracy of calculation results. So generated model of the existing building is simulated, and electricity consumption values are chosen from outputs to compare with the actual electricity consumption bills.

Table 3. Building loads

Space Type	People (people/m^2)	Lights (W/m^2)	Electric Equipment (W/m^2)
Breakroom	0.54	8.72	48
Closed Office	0.05	10.66	6.89
Electrical/Mechanical Room	–	4.84	2.91
Stair	–	4.84	–

Table 4. Schedules

Large Office Building Schedules (Fractional 0-1)		1 January- 31 December (04:00, 08:00, 12:00, 16:00, 20:00)									
Equipment	Mon- Fri	0.4	0.9	0.8	0.9	0.8	0.6	0.5	0.4		
	Sat	0.3	0.4	0.5	0.35	0.3					
	Sun	0.3									
Light	Mon- Fri	0.05	0.1	0.3	0.9	0.7	0.5	0.3	0.1	0.05	
	Sat	0.05	0.1	0.5	0.15	0.05					
	Sun	0.05									
Occupancy	Mon- Fri	0	0.1	0.2	0.95	0.5	0.95	0.7	0.4	0.1	0.05
	Sat	0	0.1	0.5	0.1	0					
	Sun	0									
VRF Availability	Mon- Fri		1								
	Sat		1								
	Sun	0									

Table 5. Heating- cooling setpoint schedules

Temperature Setup Profiles				Hourly Time Periods (04:00, 08:00, 12:00, 16:00, 20:00)		
Summer	(22 Mar-23	Heating	Mon- Sat	0 °C		
			Sun	0 °C		
		Cooling	Mon- Sat	30 °C	26 °C	30 °C
			Sun	30 °C		
Winter	(24 Sept-21	Heating	Mon- Sat	18 °C	22 °C	18 °C
			Sun	15.6 °C		
		Cooling	Mon- Sat	30 °C		
			Sun	30 °C		

Since heating and cooling demand is supplied by VRF systems; only the electricity consumption values of VRF systems are compared between the simulation results and actual bills. The MBE (Mean Bias Error) is used to quantify goodness of fit between modeled and metered data [20] [21] and annual and monthly MBE's in the 5% to 10% range provide a model that is of high enough quality to be useful for medium to large buildings. Since this study is considering annual energy consumption values, modelling and simulation processes are iterated till the simulation results reached 10% difference with the actual bill values for investigating a better performing façade in terms of energy efficiency. [22]

4. SHADING DEVICE REQUIREMENT ANALYSIS

The study deals with the whole building's simulations; however detailed analyses are covering 4 thermal zones (19, 21, 23, 25) which are chosen from the same height level of the building. These are the zones located along 11th, 12th and 13th floors. Thermal zone configuration is given in **Hata! Başvuru kaynağı bulunamadı.**3a as an elevation drawing and in Figure 3b as a plan drawing to indicate the vertical and horizontal placement of the zones with façade orientations. Though the façade's energy efficiency properties change depending on various parameters; this study emphasises effects of the shading devices. Therefore, existing shading devices are interpreted by changing their physical conditions according to solar factors. Solar elevation and azimuth angles are the main determinants affecting the physical conditions of shading devices, so that Sun path diagram in **Hata! Başvuru kaynağı bulunamadı.**4 is used for the analysis of solar angles [23].

On June 21 sun beam is affecting; eastern façade approximately between 05:00-12:00 with an elevation angle rising from 0.833o to 75o, southern façade approximately between 08:00-16:00 with an elevation

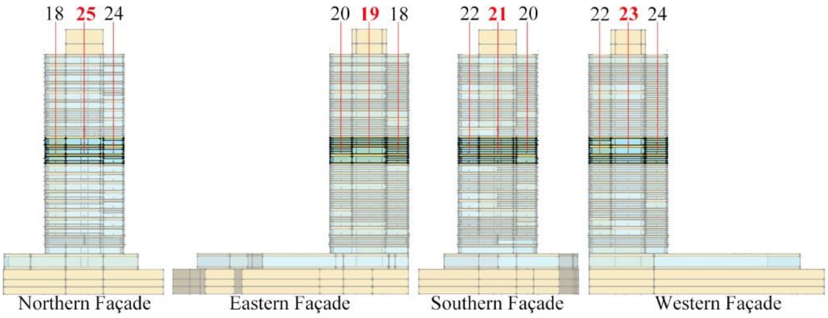

Figure 3a. Thermal zones- elevation

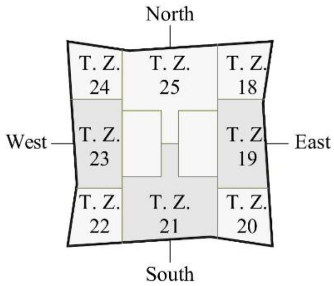

Figure 3b. Thermal zones- plan

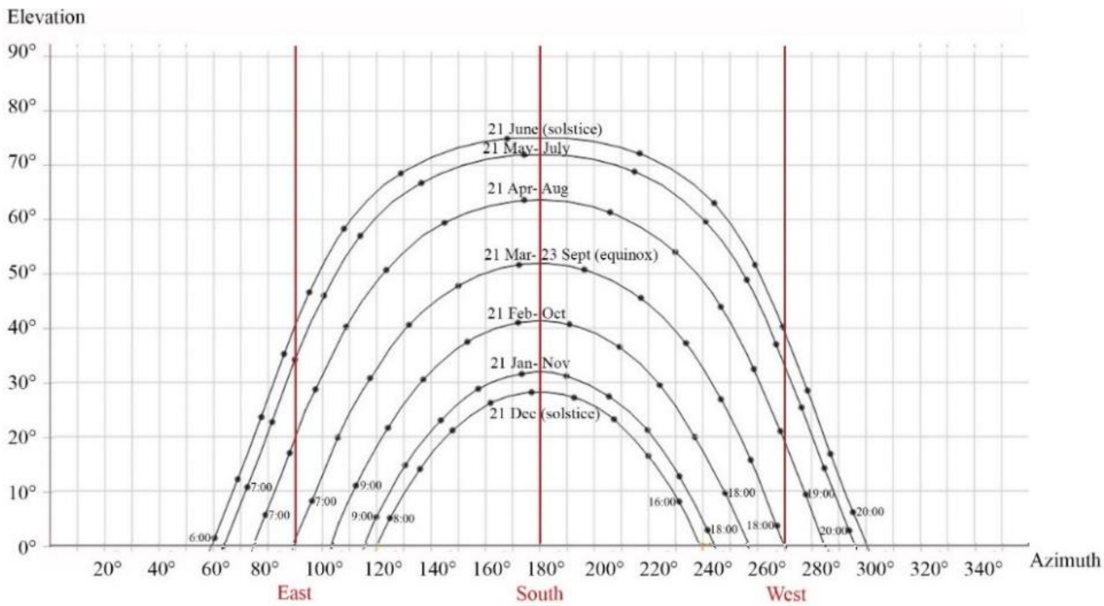

Figure 4. Sunpath diagram

Hourly values of solar azimuth and elevation angles for the equinox and solstice days are chosen from the graphic and hourly solar angles for the indicated dates are studied on plan and section schemes of the case building. Sun beam is symbolized by; yellow when it is affecting the eastern façade, red when it is affecting the western façade and blue when it is affecting the southern façade. The sun beam is affecting; the eastern façade when the azimuth angle is between 0o- 180o, the southern façade when the azimuth angle is between 90o- 270o, the western façade when the azimuth angle is between 180o- 360o.

On March 21 sun beam is affecting; eastern façade approximately between 06:14-12:00 with an elevation angle rising from 0.833o to 52o, southern façade approximately between 07:00-18:00 with an elevation angle rising from 8o to 52o and going down till 4o, western façade approximately between 13:00-18:00 with an elevation angle going down from 51o to -0.833o. (Figure 5a, 5b)

angle rising from 35o to 75o and going down till 40o, western façade approximately between 13:00-19:00 with an elevation angle going down from 72o to -0.833o. (Figure 6a, 6b)

On September 23 sun beam is affecting; eastern façade approximately between 06:00-12:00 with an elevation angle rising from -0.833 to 52o, southern façade approximately between 07:00-17:00 with an elevation angle rising from 11o to 52o and going down till 12o, western façade approximately between 13:00-17:00 with an elevation angle going down from 49o to -0.833o. (Figure 7a, 7b)

On December 21 sun beam is affecting; eastern façade approximately between 07:24-12:00 with an elevation angle rising from -0.833 to 28o, southern façade approximately between 08:00-16:00 with an elevation angle rising from 5o to 28o and going down till 8o, western façade approximately between 13:00-16:53 with an elevation angle going down from 27o to -0.833o. (Figure 8a, 8b)

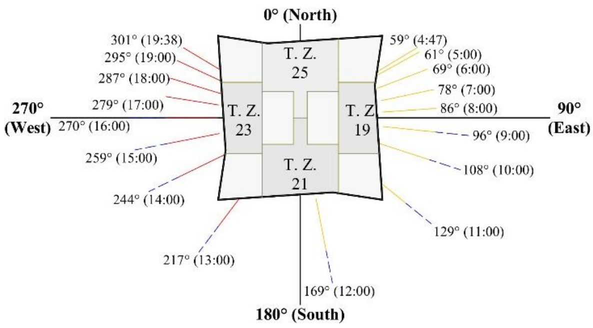

Figure 5a. June 21- Azimuth angles

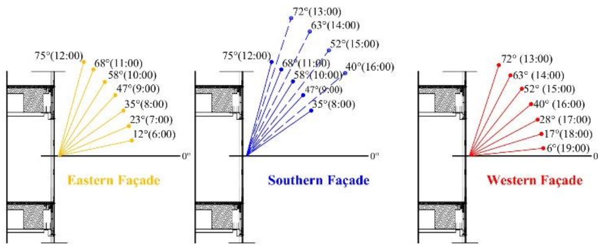

Figure 5b. June 21- Elevation angles

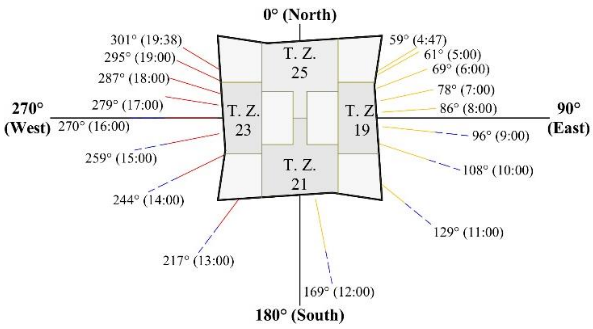

Figure 6a. June 21- Azimuth angles

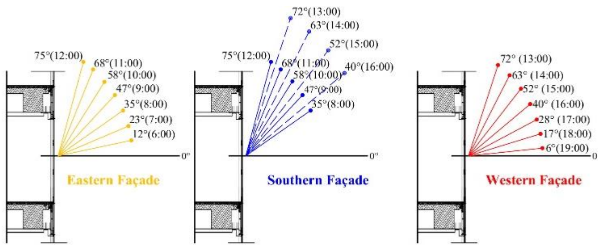

Figure 6b. June 21- Elevation angles

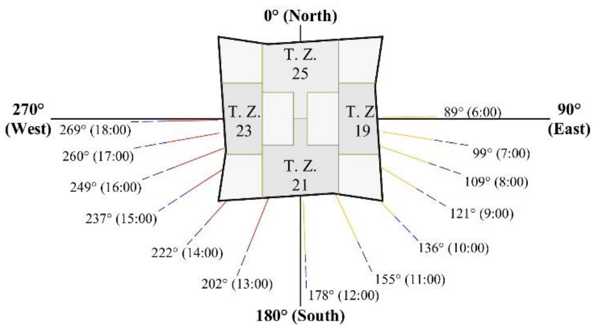

Figure 7a. September 23- Azimuth angles

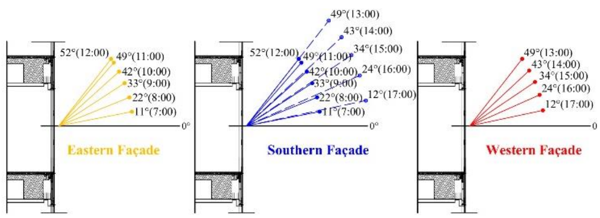

Figure 7b. September 23- - Elevation angles

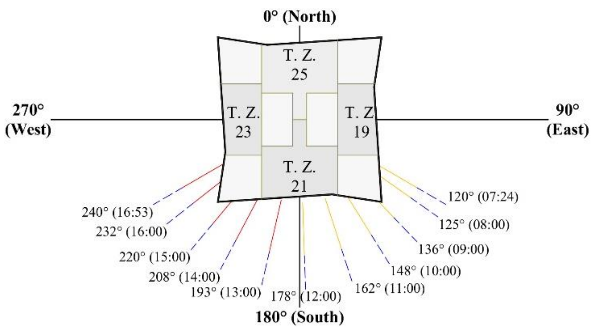

Figure 8a. December 21- Azimuth angles

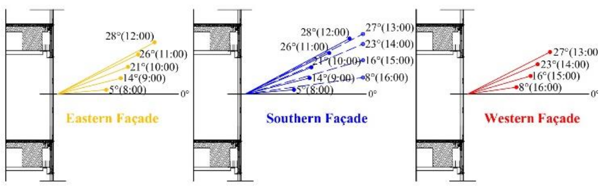

Figure 8b. December 21- Elevation angles

Given on plan and section schemes of the case building, hourly values of elevation angles for the equinox and solstice days are studied from Figure 5a-5b, Figure 6a-6b, Figure 7a-7b and Figure 8a-8b. The collected data for elevation angles is presented as a graph given in Figure 9.

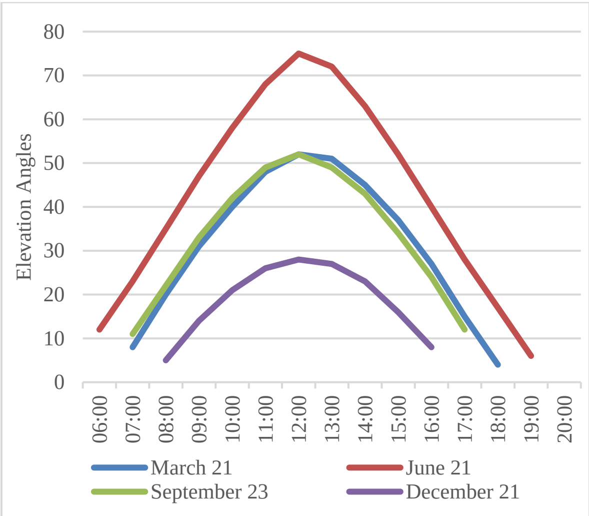

Figure 9. Hourly elevation angles

In second phase of the shading device requirement analysis; case building is modelled without shading devices and 'exterior windows total transmitted beam solar radiation energy (J)' values of the Thermal Zones 19, 21, 23 and 25 are studied from simulation results. To understand the seasonal changes of sunbeam elevation angles; solstice and equinox days are used as reference days and results are presented in Table6.

Regarding to the data in Table 6; east and west oriented façades are mostly affected with high solar radiation in Summer because of the low solar elevation angles of sunbeam that passes through the façade to interior spaces.

For south facing façades it is changing as sunbeam grazes the façade due to its high elevation angle and north facing façades are just affected by the indirect solar radiation. As a result, shading devices are interpreted for both seasons in only south facing façades. Shading devices of East and West oriented façades are considered only for Summer. Apparently North façade is facing direct sunbeam for a short time while the sun is rising up and going down which can be neglected; so that it is excluded from the field of this study.

Considering the orientation of the case building, sunpath diagram analysis results and beam solar radiation energy values are collected. The maximum elevation angle is 75o on 21st of June for the eastern and western façades. Since a 60o elevated shading device can block the sun beam coming with 75o elevation angle. Also the shading devices located with an elevation angle less than 20o are acting as if it is completely closed. (Figure 9) So that 20o and 60o are accepted as the minimum and maximum elevation angles for this study and 40o is aslo considered as the medium elevation angle for the shading devices.

CASD proposal is determined according to the changing shading seasons from Summer to Winter for each façade orientation considering daily shading hours. (Table 7) Eastern and western façades are shaded only in Summer season with the shading devices that have 3 modes as 20o, 40o, 60o, while southern façade is shaded in 2 modes as 40o and 60o in Summer and 20o in Winter Season.

Table 6. Maximum beam solar radiation energy values transmitted from the windows, with no shading devices

Façade Orientation	Max. Beam Solar Radiation Energy (J)							
	March 21		June 21		September 23		December 21	
	Time of Max. Value Reached	Max. Beam Solar Radiation Energy (J)	Time of Max. Value Reached	Max. Beam Solar Radiation Energy (J)	Time of Max. Value Reached	Max. Beam Solar Radiation Energy (J)	Time of Max. Value Reached	Max. Beam Solar Radiation Energy (J)
East	08:30	3.70415e+06	08:30	3.78626e+06	08:30	3.60578e+06	09:30	1.72701e+06
South	11:30	3.61313e+06	11:40	495445	11:30	2.71133e+06	11:30	4.75947e+06
West	15:40	3.2808e+06	17:30	2.87148e+06	14:50	2.92159e+06	14:50	1.96825e+06
North	-	0	18:00	176068	-	0	-	0

Table 7. CASD elevation angles

Façade Orientation	Shading Season	Daily Shading Hours/ Elevation Angles												
		07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
East	Summer	20o		40o	60o			–						
South	Summer	–		40o	60o				40o		–			
	Winter	20o									–			
West	Summer	–					60o		40o			20o		–

4. SIMULATION RESULTS AND COMPARISONS

Position of the shading devices are driven out from solar elevation angles and shading availability decisions are driven out from solar azimuth angles as the required shading characteristics. Apart from the adaptivity parameters, quantity of the shading elements has changed with the proposed façades. While existing building has a designed layout with some reductions in shading devices regarding to the orientation, in the proposal northern façade has no shadings, though east, south and west oriented façades are fully shaded. Shading devices are placed with the same construction detail in Figure 1, keeping the size in all proposals same with the existing devices.The model with the existing shading devices is used for validating the model and energy performance comparison of the case building with the existing and proposed shading devices.

The model with no shading devices is representing the existing building without shading devices to be used in shading device requirement analysis through the 'Exterior Windows Total Transmitted Beam Solar Radiation Energy (J)' values chosen from the simulation results. Considering the 'shading device requirement analysis' results; CASD proposal is presented for each façade orientation with the changing shading device angles based on hourly and seasonal solar movements.

Regarding to the over- heating problems of an exiting building; glazed curtain wall façade is detected as the reason affecting heating and cooling loads directly. Since heating and cooling demand of the case building is supplied by VRF systems, electricity consumption is considered as the building energy performance indicator in this study.Annual Electricity consumption values are used for verification of the created simulation model through the comparison with actual electricity bills. Then the electricity consumption values are compared over the building model for the status with no shading devices, with the existing shading devices and with the proposed CASD. Table 8 presents electricity consumption values per m^2 used for 34000 m^2 closed area in total, including heating, cooling and fan usages of the VRF systems.

Monthly and annual electricity consumption values of the case building are presented in Table 8. Since the actual bill is giving the total consumption of heating, cooling and fans; the total value data of the simulation model is used for validation. As it is mentioned before, there is 10% difference which can be seen in Figure 10 clearly.

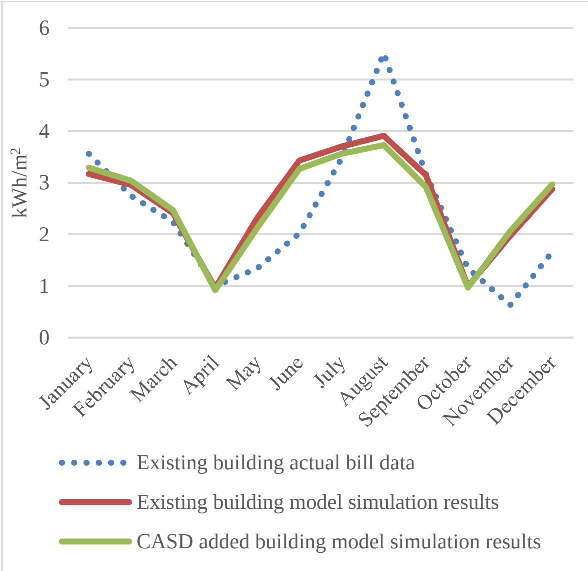

Figure 10. Total Electricity Consumptions

In reality April, May and October are the months without any climatization in general, but the simulation calculates as if there is cooling for these months depending on the climate data. Also for November and December, estimated heating electricity consumption is higher than the actual bill values. (Figure 11) In total highest electricity consumption is in August for both simulation results and actual bill. But it is seen that real cooling electricity consumption is higher than the estimated values in simulation. (Figure 12) These differences are creating 10% deviation in the total results of this study. As the climate data is generated by statistical data for significant periods, the effects of peak values and extreme days are underestimated so that causes differences in between real data and simulation results.

Table 8. Electricity consumption values (kWh/m^2)

Consumption source	Consumption source	Monthly electricity consumptions (kWh/m^2)												Annual total
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
Existing building actual bill data	Total (Heating+Cooling+Fans)	3,56	2,75	2,24	1	1,34	2,02	3,47	5,51	3,17	1,34	0,63	1,66	28,69
Existing building model simulation results	Heating	2,48	2,31	1,69	0,01	0,00	0,00	0,00	0,00	0,00	0,09	1,26	2,18	10,02
	Cooling	0,01	0,01	0,01	0,29	1,60	2,75	3,01	3,19	2,46	0,22	0,03	0,01	13,58
	Fans	0,69	0,63	0,71	0,66	0,71	0,69	0,69	0,72	0,69	0,69	0,69	0,69	8,24
	Total	3,17	2,96	2,41	0,96	2,32	3,43	3,70	3,91	3,15	0,99	1,97	2,88	31,85
CASD added building model simulation results	Heating	2,60	2,40	1,75	0,01	0,00	0,00	0,00	0,00	0,00	0,12	1,36	2,28	10,53
	Cooling	0,01	0,01	0,01	0,25	1,41	2,58	2,87	3,01	2,24	0,17	0,02	0,01	12,59
	Fans	0,68	0,63	0,71	0,66	0,71	0,69	0,69	0,71	0,69	0,68	0,68	0,68	8,22
	Total	3,29	3,04	2,47	0,92	2,13	3,27	3,56	3,73	2,92	0,97	2,06	2,97	31,34

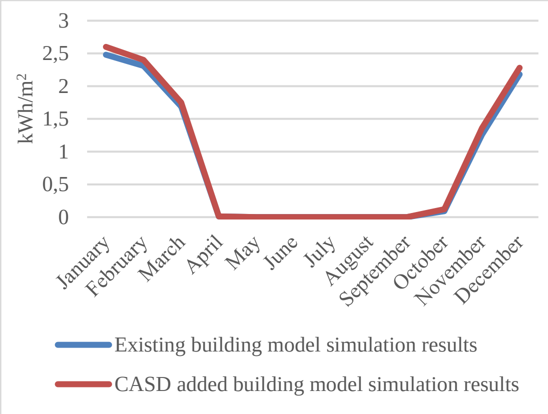

Figure 11. Heating Electricity Consumptions

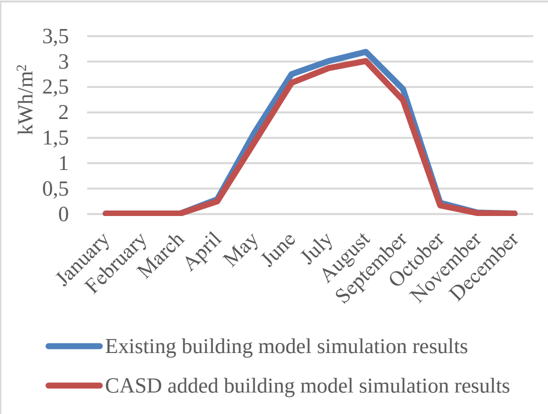

Figure 12. Cooling Electricity Consumptions

In **Hata! Başvuru kaynağı bulunamadı.**9, façades are studied through 'Zone exterior windows total transmitted beam solar radiation energy values (J)' in order to understand the solar effects on a zone-based analysis.

Following the principle of sunpath diagram analysis; equinox and solstice days are taken as reference to understand the dramatic solar effects on building façade. So maximum values of 'Zone exterior windows total transmitted beam solar radiation energy (J)' are chosen for each façade orientations relevant to time of the peak point. To understand when the solar effect is maximum on a façade without any prevention, simulation results of the model with no shading devices are used. The peak values of 'zone exterior windows total transmitted beam solar radiation energy (J)' with no shading devices are as follows;

- East facing façade of thermal zone 19:
at 8:30 on June 21,
- South facing façade of thermal zone 21:
at 11:30 on December 21,
- West facing façade of thermal zone 23:
at 15:40 on March 21.

As a result of the given analysis; for eastern façade proposed CASD decreases solar radiation from 3.78626e+06 to 1.58989e+06, for southern façade from 4.75947e+06 to 2.32675e+06 for the days with peak values. But for the western façade CASD proposal gives the same peak value as 3.28287e+06 on March 21 at 15:40. However CASD proposal is decreasing the solar radiation values approximately 50% on June 21 and September 23 for Eastern façade, on March 21 and December 21 for Southern façade and on June 21 for Western façade.

Table 9. Zone exterior windows total transmitted beam solar radiation energy values (J)

Façade Orientation	Shading Status	March 21		June 21		September 23		December 21	
		Time of Max. Value Reached	Max. Beam Solar Radiation Energy (J)	Time of Max. Value Reached	Max. Beam Solar Radiation Energy (J)	Time of Max. Value Reached	Max. Beam Solar Radiation Energy (J)	Time of Max. Value Reached	Max. Beam Solar Radiation Energy (J)
East (Thermal zone 23)	No Shading	08:30	3.70415e+06	08:30	3.78626e+06	08:30	3.60578e+06	09:30	1.72701e+06
	Existing Shading	08:30	3.35447e+06	08:30	3.13395e+06	08:30	3.16174e+06	12:21	1.54384e+06
	CASD	08:30	3.70415e+06	08:20	1.58989e+06	08:30	1.70737e+06	09:30	1.72701e+06
South (Thermal zone 21)	No Shading	11:30	3.61313e+06	11:40	495445	11:30	2.71133e+06	11:30	4.75947e+06
	Existing Shading	11:30	1.70272e+06	-	0	11:30	920126	11:30	3.59462e+06
	CASD	11:30	1.25453e+06	-	0	11:30	591872	11:30	2.32675e+06
West (Thermal zone 23)	No Shading	15:40	3.2808e+06	17:30	2.87148e+06	14:50	2.92159e+06	14:50	1.96825e+06
	Existing Shading	16:00	2.91698e+06	17:30	2.64245e+06	15:00	2.38171e+06	15:00	1.77348e+06
	CASD	15:50	3.28287e+06	17:30	1.52222e+06	15:20	1.19983e+06	14:50	1.96825e+06

5. CONCLUSION

Since the 'best performing façade' is still an indefinite notion in terms of energy efficiency, this study aims to propose a methodology to propose a CASD for any case building. The study focuses on managing the effects of a façade on building energy performance; interrogating the features that are needed and the features that should be avoided. Solar movement is determined to be the main factor effecting the façade decisions relevant to the requirements of the indoor environment, so the topic is discussed within the specific parameters of the case building.

An existing case building is modelled by using OpenStudio software in detail of the actual project data. Annual electricity consumption values that are discussed as heating and cooling energy consumptions are accepted as the building energy performance indicators. Through the analysis on simulation results, effects of shading devices on building energy performance are presented. Results are analysed both in all building and thermal zone scales through different parameters. Based on the stated overheating problems of the south facing offices, the study focused on the shading devices assembled to the glazed façade. Regarding to the seasonal solar movement; case building's shading device requirements are determined in detail of shading device elevation angles and hourly/ daily shading schedules. Also, 'exterior windows transmitted beam solar radiation energy' parameter is examined for seasonal periods to understand the shading need of façades depending on orientation. These analyses came out as; for north oriented façades shading is not a requirement in any time of any season; east and west oriented façades require shading devices only in summer where the south oriented façades require shading devices both in summer and winter.

Considering the location of the case building, climate conditions create cooling demand rather than the heating demand. So, the focus of this study is the over-heating problems of the building especially in southern façades which causes high cooling electricity consumption values. It is clear that existence of the shading devices is affecting heating and cooling energy consumptions inversely. When the effectiveness of shading devices increases, benefit of solar effect on heating loads decrease. That is why the shading devices increase the heating loads even if they are climate adaptive. Since focus of this study is over- heating problem of the case building, decreasing the cooling demands is pointed out as a solution. So, CASD is proposed with hourly adaptive shading device schedules which are placed with seasonal adaptive shading device angles specific to the façade orientations.

Another important outcome of this study comprised due to the solar elevation and azimuth angles; southern façades are facing the Sun with a higher elevation angle (47°- 75°) in summer season, compared to the winter sun which has a lower elevation angle (5°- 28°). So that beam solar radiation energy is much effective in winter compared to summer for south facing façades and this is the most crucial output of the study. Consequently, by proposing CASD for an existing case building, this study reveals a solution for a stated problem, which is the occupants' compliant about the overheating problems of the case building.

The presented methodology of this study is applied on an existing building to support the literature of the study field by giving simulation results of building energy performance calculations that are comparable with the real data. Since the concept of climate adaptive façades is not mature enough to be applied and examined it is not supported by sufficient information yet. This study is expected to examine the effects of CASD on building energy performance through the outputs derived from simulation results of an existing building; so that the outputs can be compared with real data. However, the study covers the parameters of a case building, presented methodology can be applied on different building types and different locations. Also, the scope of the study can be varied by changing the minor parameters. In further studies, CASD can be studied considering the monthly changes of the solar angles.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Hande ODAMAN KAYA: Modelled the case building and performed the simulation.

Müjde ALTIN: Contributed to the evaluation of simulation results and edited the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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