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Performance optimisation of office buildings in the context of overheating and daylighting with external shadings

Gizem Izmir Tunahan

September 2017

Submitted in partial fulfilment of the MSc degree in

Sustainable Building: Performance and Design

Oxford Brookes University

2017

This thesis is being submitted to the Department of Architecture at Oxford Brookes University in partial fulfillment of the requirements for the degree of MSc.

This thesis is the result of my own independent work, except where otherwise stated. Other sources are acknowledged by explicit references.

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Abstract

Overheating, which refers to feel uncomfortable because of temperature increases in a building, has become more important due to the climate changes. In order to reduce unwanted heat gain and glare while maintaining high light quality in the building, solar shading devices can be used as a solution and all shading devices have considerably different effects on the visual relationship with outside, thermal comfort and daylight level of the building. Except for their contribution to occupant physical and psychological satisfaction, they provide a significant energy profit by reducing cooling loads as a financial benefit. This study aims to investigate balancing cooling and lighting energy demand in office buildings in Izmir, Turkey by using external shading devices whilst considering the future implications. For this purpose, some quantitative analysis methods were developed to reduce energy loads and improve occupant satisfaction. Drawn typical office building in Designbuilder software tool was simulated for predetermined external shading types as overhang, louvre and sidefin and their effective factors for each orientation. Then, the results obtained from simulations were compared and the best values for each factor were selected on the basis of direction. After the identification of the best factors for each shading devices, the best ones were compared to identify directional requirements. At the end of this process, for each direction, the best shading option with suitable factors was identified and the optimum option was created by combining all best options. Consequently, 12.60% of the reduction in cooling and lighting load was obtained while maintaining occupant satisfaction at high levels in offices after three hundred simulations on the individual, directional and combinational based. Also, the main limitation of this study was that optimisation progress was conducted by defining some variables and values manually differing from optimisation software users, therefore it can be possible to reduce lighting and cooling loads more by selecting the exact optimum points automatically.

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Gizem IZMIR CIRAK

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Introduction to the chapters

This thesis is structured as follows:

In **Introduction** section, the purpose of the research and the rationale of the study are introduced on the based on simple introduction

Literature review focuses on the overheating problem and shading devices deeply and aims to give insight into the reader about them

Methodology describes how the data is collected, which methods are used and why, how the steps are applied and how the results are analyzed to answer the research question

In **Results**, all results obtained from the Section 3 are presented by grouping

Discussion and Conclusion answer the main question and how you come to this conclusion supported by discussions, gives some recommendations for further research and explains the limitations of the research, followed by the Referencing list and Appendices.

1. Introduction

1.1. Context of the study

In order to create well-design and environment-friendly buildings, many factors should be considered carefully such as building form, orientation, materials and other factors. Besides, post-production stage should be considered by covering the energy consumption and indoor environmental quality. This is because, they have a great impact on occupant satisfaction in terms of physical, psychological and financial aspects. For instance, window opening and the proportion of glazing area are very effective in the building operation in terms of heating, cooling and lighting energy consumption and also, these factors are determinative indirectly for how much people are happy while living or working in that building (Strathclyde University, 2016).

When these factors are evaluated in the office buildings category, use of glazing façade becomes more crucial because of their large transparent components because of the significant effect of solar gain on thermal and daylighting performance in both summer and winter (Atzeri et al., 2010). Therefore, external shading devices have a potential to minimise energy consumption and improve occupant satisfaction throughout an office building which has large transparent façade.

1.2. Significance of the study

Large glazed facades have become more popular over the past few years in new buildings, especially in the Mediterranean area. As a consequence of this situation, sun rays can enter inside through glazed façade easily and therefore the air temperature reaches to high temperatures which have the possibility to affect indoor environmental quality on occupant well-being and comfort. As a result of uncomfortable thermal conditions, glaring increases, indoor air quality decreases and correspondingly, the cooling load has a tendency to increase (Freewan, 2014). For this reason, in order to reduce the possibility of overheating and extreme cooling load, taking precaution is necessary by shading the windows with some internal or external devices (Iyengar, 2015). Thus, it can be made possible to control solar gain and provide enough daylight without overheating, while supplying good thermal and daylight conditions and also, maintaining the external view for better human performance in offices (Kaita and Alibaba, 2017).

Recommended external shading devices as a solution against to overheating, are divided into two types as fixed to the outside of the window or attached to building envelope and their manageable parts are made of wood or metal generally, also they can be used as fixed or movable according to preference (CLEAR, 2014). Although they offer many alternatives as materials, application ways and usage options, external shading devices require many design considerations such as the harmony with existing building style and structure. Also, their slat angle, the distance between slats, thickness and width of the slat and also, directional and back diffuse of them have great importance during the design in terms of the effects on energy consumption and indoor environmental quality (Freewan, 2014).

1.3. Research problem

The research problem covers the contributions of external shading devices on cooling and daylighting requirements of the office buildings and includes their energy saving differences according to the directions and their features such as shading slats' position, angle and dimensional differences. Although there are many studies on this field, there is a lack of comprehensive study that aims to optimise lighting and cooling requirement depending on the direction by simulating the base case model with all type of external shading devices, changing predetermined features and comparing their results.

1.4. The rationale for this study

According to research conducted by Duttaa, Samantaa and Neogib (2016), heating, cooling and artificial ventilation systems cause a considerable amount of energy consumption. IPPC studies (2015) show that energy consumption arising from heating, cooling and artificial ventilation systems accounts for around 43% and 51% of total energy expenditure in the commercial and residential buildings respectively. For the purpose of reducing cooling and artificial ventilation consumptions by blocking the heat gain from outside, internal or external shading devices can be very effective solution but the studies show that the performance of internal shading devices are generally lower than external shading devices due to redistribution of entering heat into the room (Ye et al. ,2016). For this reason, the more effective one, external shading devices will be improved in this study.

On the other hand, shading devices have potential to be used for reducing indoor temperature to comfort level in hot climates, supplying good indoor quality and decreasing cooling and lighting energy consumption indirectly. According to Dutta, Samanta and Neogi (2016), 9.8% of total consumed energy annually and even 14.9% of total consumption in June by showing a peak can be possible to save by using external shading devices in an effective way. Otherwise, the amount of light has a great impact on human physiology and psychology directly, therefore external shading devices become more important and should be considered carefully (Gugliermetti and Bisegna, 2004).

The research aims to introduce the external shading devices and their differences and to improve them to minimise energy consumption of the buildings while maintaining occupant satisfaction at high levels in Izmir, Turkey. This is because, the city of Izmir, which has a Mediterranean climate, is located on the Aegean Sea and summers are hot and sunny (Climatestotravel, 2017). Therefore, in order to prevent overheating problems of the buildings there, this study is considered necessary.

1.5. Research question

The main research question consists of how many percentage external shading devices can reduce to cooling and lighting energy consumption of the office buildings depending on the shading type, features and applied direction. Also, research question covers whether there is a possibility to optimise the lighting and thermal comfort conditions in terms of energy efficiency and occupant satisfaction or not.

1.6. Research aim and objectives

The aim of this research is to investigate possible solutions that add further knowledge to the question of which type of external shading device should be used for each direction and what should be its properties in order to save energy and improve thermal and daylight performance while maintaining visual comfort in Izmir.

This thesis also aims to benefit from external shading devices by improving them to minimise energy consumption and provide occupant satisfaction by optimising the thermal and lighting conditions in the buildings. The benefit of this research provides a better understanding of the external shading devices and their contributions to buildings and occupants.

In order to answer the research question, there are four key objectives that are to be delivered through the project:

Objective 1: A typical office building in Izmir will be drawn and its energy consumption will be calculated in a dynamic software

Objective 2: External shading device types and their variances will be identified and they will be applied to the typical building to figure out the impact on thermal and daylighting conditions of selected building behaviours

Objective 3: Change of lighting and cooling requirement of the building for each variance and each direction will be observed and compared each other

Objective 4: Variances giving the best result will be selected and combined in order to see their overall effect and recommend for further research

2. Literature review

2.1. Overheating Problem

2.1.1. The definition of overheating

The term of overheating refers that occupants feel uncomfortable because of temperature increases in a building. Nowadays, it has become more important due to the climate change, the urban heat island effect, household equipment and increasing proportion of glazing to total façade area. The reason why it has become more important for Europe and the UK is that according to CIBSE's studies (2015), some cities such as London have shown higher ambient temperatures rather than the last 30 years and homes have converted into uncomfortable places especially in summers due to the deficiency of air conditioning systems. Therefore, this climate change has caused the current overheating problems by bringing economic, cultural and politic problems with unpleasant indoor air conditions (Lomas and Porritt, 2016).

2.1.2. Effective factors on overheating occurrence

According to CIBSE report (2015), overheating is not caused by only one factor and it is come to exist by combinations of some factors. These factors are:

- Climate of the building location and urban heat island effect
- Features of building walls, facades, insulation
- Occupant behaviours
- Inconvenient building orientation causing much solar gain

- Unshaded facades and absent shading elements like trees
- Not opened windows due to noise and security issues
- Type of property and the location of the flat in the building

2.1.3. Performance of overheating analysis

Although the heat wave of the regions changes depending on the location and typical climate, when they are compared with each other, the hot temperatures in one region can be regarded as cold temperatures for the other one. Essentially, the heat wave is a term describing to show higher temperatures than average temperatures for that region during three to five days. According to The World Meteorological Organization, highest and lowest temperatures should be specified depending on the region.

Region	Day max (°C)	Night min (°C)
North East England	28	15
North West England	30	15
Yorkshire & Humber	29	15
East Midlands	30	15
West Midlands	30	15
East of England	30	15
South East England	31	16
London	32	18
South West England	30	15
Wales	30	15

Figure 1: Heat wave threshold values for England and Wales

As can be seen in Figure 1, there are some threshold values for England and Wales defined by considering 1 June to 15 September period by the Department of Health and the Welsh Assembly. Moreover, they claim that these temperatures have a substantial effect on people's health conditions if at least two sequential days are over the thresholds. Correspondingly, many countries have adopted these temperatures

according to their climate conditions. The overheating is defined as five sequential days at or over 35°C and three sequential days at or over 40°C in Adelaide, South Australia. On the other hand, France accepts each three temperatures over averages during summer as an overheating period (Bre, 2017).

According to the study done by Good Homes Alliance and the Zero Carbon Hub, overheating, which becomes more crucial from day to day, causes continual warming in the buildings and these airtight and uncomfortable places can be risky for people's health. Overheating analysis is invaluable because it is possible to take precaution and improve the indoor air quality against predicted problems during the design process.

Overheating analysis made in order to achieve good indoor air quality is performed by using some Dynamic Simulation Modelling software which has some abilities to analyze occupied spaces during occupied hours and their performance is evaluated against CIBSE criteria set created by Chartered Institute of Building Services Engineers.

Why overheating analysis is considered as necessary is to achieve BREEAM certificate which makes thermal comfort obligatory, meet the demand of designers for a reduction in overheating risk, meet the requirement of the planning process or just to get good indoor conditions (Buildenergy, 2016).

2.1.4. Overheating analysis methods

After the first papers monitoring to use different criteria to evaluate whether the buildings are overheated or not had been published, overheating evaluation criteria were developed in the late 1980s for different countries as different criteria. Then, the Chartered Institution of Building Services Engineers (CIBSE) provided design summer year, which is 'the most appropriate year of weather data to assess the summertime cooling needs of buildings'(Cibse,2014) to specify overheating assessment criteria for

the UK in 2002 and updated it in 2016. Also, this criterion has been started to assess Passivhaus design proposal (Lomas and Porritt, 2017).

According to CIBSE 2006 approach, overheating was not evaluated as based on single limiting temperature. If 5% of occupied working hours show over 25°C or 1% of occupied working hours indicate temperatures over 28°C, it means that the building is overheating. This situation was not approved by some people because of inadequate results and dependence on the limited type of building and climate condition. Also, CIBSE 2006 approach could not harmonize with the international standards, especially in naturally ventilated buildings. On the other hand, it was not created by providing it to consider occupant behaviors.

After that, adaptive comfort approach giving more convenient results was developed. Currently, it has been accepted as a standard approach to indicate target temperatures in the buildings ventilated naturally whose indoor conditions are difficult to control. Also, it differs with the ability to apply to all buildings from previous versions.

In order to reach acceptable indoor conditions, either the occupant adapts the building or the building provides suitable conditions to the occupant in climatic, social, economic, architectural or cultural context. Therefore, buildings should be designed as providing good indoor air conditions and they should allow people controlling environment (Nicol,2016).

The thermal comfort which is significant for occupant satisfaction specifies whether the occupant is comfortable in the building or not. Its measurement is very difficult because it depends on person to person. If the flowing heat from occupant's body is more than entering his body, his sensation will be cold and if it is opposite, his sensation will be hot. Overall, there are six effective factors determining the thermal comfort as depending on occupant's features and environmental conditions. These are the metabolic rate, clothing insulation, air temperature, air velocity, radiant temperature and relative humidity, and also individual experiences and occupant physiology are important too (Autodesk,2016).

The heat gain reducing thermal comfort level and making the building uncomfortable during the overheating season is related to different factors externally and internally. While external heat gains depend on the solar gains, internal heat gains can arise from many factors such as occupancy, lighting, maintenance and equipment. In order to minimise energy consumption for cooling, these heat gain sources should be considered carefully and it should be taken precaution to reduce them (Enrei,2016).

For the purpose of expressing satisfaction with the thermal comfort conditions, the predicted mean vote was developed by Fanger and later adopted as an ISO standard. The predicted mean vote sensation scale (See in Figure 2) was constituted as collecting data from plenty of people's experiences in different thermal conditions. A technical correlation was created by using the data depending on environmental and physiological factors (Autodesk,2016).

Value	Sensation
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

Figure 2: Predicted Mean Vote Sensation Scale (Colorado,2015)

According to ASHRAE 55, the convenient predicted mean vote (PMV) range should be between -0.5 and +0.5. In order to understand the satisfaction of thermal comfort, predicted the percentage of dissatisfied (PPD) is used by assuming zero as the best thermal comfort condition and as long as PMV moves from zero, PPD value becomes more significant (Autodesk,2016).

The predicted mean vote (PMV) constitutes the average result by collecting data from many people. Natural comfort conditions will distribute to some people because thermal comfort sensation changes depending on person to person. Figure 3 shows that

there is an empirical relationship between the percentage of people dissatisfied (PPD) and predicted mean vote (PMV) (Colorado,2015).

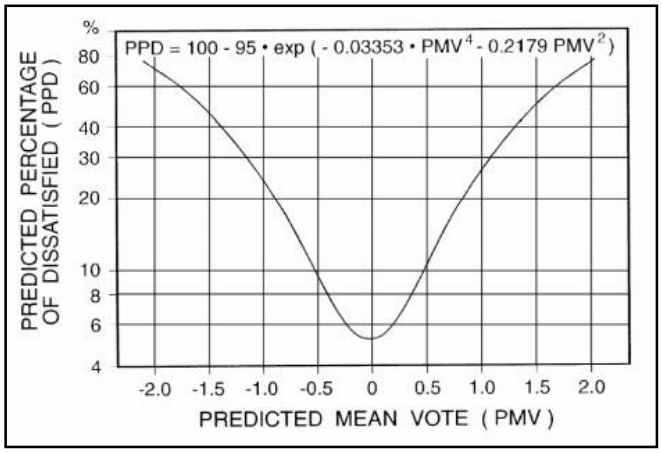


Figure 3: Percentage of people dissatisfied (Colorado, 2015)

CIBSE TM52 (The Limits of Thermal Comfort: Avoiding Overheating in European Buildings, 2013) which is an adaptive comfort tool is widely used in the UK and Europe with the three-criterion system to evaluate the buildings against overheating risk. According to CIBSE three-criterion system, in the case of failing in any two of three criteria, the building is regarded as overheating (Ies, 2016). Generally, how many hours exceed the comfort temperature threshold, how much temperature increase is seen in a day and what is its' duration, and also what is the temperature is regarded as an overheating level constitute CIBSE criterion system as significant factors (Buildenergy,2016).

- Criterion 1

  According to the first criterion, the occupied hours showing more than 1 K over the adaptive comfort should not be more than 3% during the non-heating season which is defined by the CIBSE between 1 May and 30 September.

- Criterion 2

  The second criterion depends on the frequency of overheating and defined thresholds in any day cannot be exceeded more than 6 degree-hours a day.

- Criterion 3

  Criterion 3 requires that any occupied hour should not be more than 4 K over the defined threshold (Ies,2016).

2.1.5. The ways to reduce overheating risk and possible solutions

Generally, it is possible to reduce overheating risk by selecting convenient methods. If any property is seen as at risk for overheating, applying external shading devices on east, west and south facing windows to decrease solar gain or improvement of insulation in internal and external walls can be proposed as a general solution. When this issue considered in detail, there are three solution types depending on the financial potentiality.

<u>Low-cost solutions</u>

- Application of internal shadings or curtains to provide the reflection of the sunlight
- Application of reflective paint to external walls or roofs
- Reduction in internal heat gains depending on the occupants, lighting and home equipment. Also, insulation of some warm air sources such as hot water tank or pipework can be considerable.

Medium-cost solutions

- Application of external shading devices can be used as an effective solution but their seasonal sensitivity and occupant control mechanism should be considered
- Application of static external shadings above the windows
- Application of solar reflective coatings can be effective for top floor flats

High-cost solutions

- External insulation with the internal application during protection of thermal mass in the rest of the building in where it is necessary to reduce gaining heat from the sun (CIBSE, 2015).

2.1.6. Required thermal and lighting conditions for offices

In terms of occupant satisfaction in office buildings, according to Canadian Centre for Occupational Health and Safety (2016), the data obtained from Guideline on Office Ergonomics show that the temperature of the workplace should be maintained between 23°C and 26°C during the summer period and the range of temperature should be between 20°C and 23.5°C within the winter period. Although there is no identified existing lowest humidity limitation for thermal comfort, it is recommended that the relative humidity should be between 40% and 70% not to affect thermal comfort contrastingly. On the other hand, office workstation design report prepared by WSPS (2011), the lighting level in the range of 300- 500 lux is accepted in office buildings as the most appropriate level to maintain productivity. Conversely, Kellwood (2016) recommends that the lighting level should be 500 lux in general offices.

Furthermore, cooling and lighting, which has a significant role in occupant satisfaction, contribute to energy consumption as well. In a typical office building, lighting, cooling and heating account for approximately 70% of the total energy consumption (PUD, 2016). Also, lighting and cooling energy consumption annually in office buildings and their contribution percentage to total consumption can be seen in Figure 4 and 5. The percentage differences between Figure 4 and 5 arise from the location of the office buildings investigated. While annual energy consumption results of an office building in the UK are being represented in Figure 4, Figure 5 shows the percentage of the factors that contribute to energy consumption an office building in the US. Consequently, a generalization of energy consumption for office buildings is not possible and it depends on many factors like location most importantly.

	Fossil fuels (PJ)	Electricity (PJ)	CO_2 (kT)
Heating	46	5	3680
Hot water	5	0	469
Catering	3	3	370
Light	-	16	2238
Cooling	-	11	1319
Small power	-	2	250
IT	-	12	1031
Other	-	2	184
Process	-	3	7
Unknown	-	0.3	121
Total	**54**	**56**	**9669**

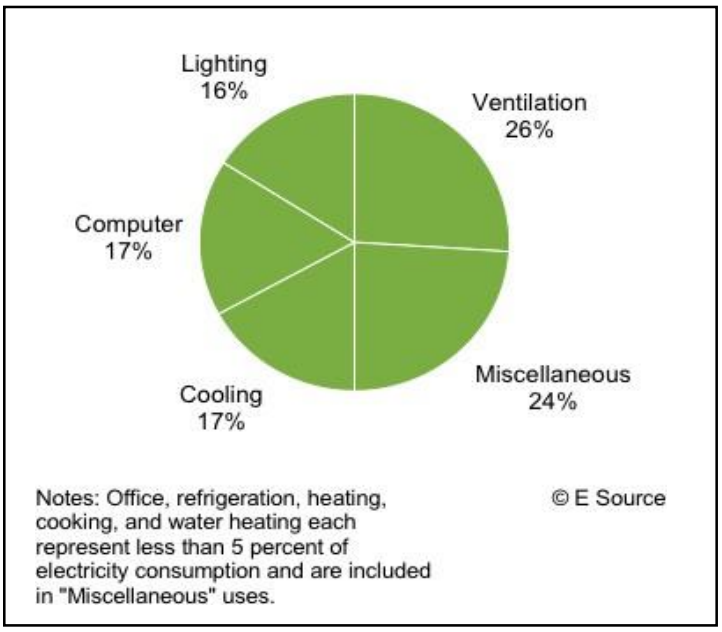


Figure 4: Energy consumption and CO2 emissions in the UK commercial offices (ACE, 2003)

Figure 5: Electricity and uses in offices (PUD, 2016)

2.1.7. The importance of overheating and lighting level on occupant satisfaction

Jensen (2016) points out that lighting level plays a big role in providing occupant satisfaction and increasing working performance. A research conducted by the American Society of Interior Design indicates that 68% of occupants are not pleased with lighting level in their offices due to dim or harsh lighting level. Dim light level as a part of dissatisfaction can play a significant role in occupant productivity in many ways such as health problems like eye strain and headaches, lack of concentration and drowsiness. On the other hand, according to Roche, Dewey and Littlefair (2000), the surveys and questionnaires conducted with 270 occupants in sixteen office buildings show that although most of the occupants are affected daylight positively while working, they indicate that they feel dissatisfied with too much lighting especially if average daylight factor is above 5%. In case of high lighting levels, complaints from occupants due to the sun and glaring may be increased, so it can affect their working performance as well. In order to avoid excessive lighting level, shading devices and control of lighting can be possible solutions.

Similar to extreme lighting levels' unfavorable effects, according to Zero Carbon Hub report (2016), the increase of some health problems may be seen due to overheating problems in the buildings, such as dehydration, prickly heat, heat cramps, heat oedema, heat syncope and heat rash. In addition to the physical effects of overheating, it has a risk to reduce occupant productivity and concentration level. Also, high temperatures, which may lead to stress, illness and even death, can result in potential problems from mental health problems carrying risk in suicide to heat exhaustion.

2.2. Shading devices

2.2.1. Types of shading devices

Sun shading devices made of any mechanical system or material are applied to the building internally or externally. The main reason to use them is to provide good indoor conditions, which is cool in the summer and warm in the winter. They are good solutions to reduce cooling loads and energy costs by decreasing the solar gain. Therefore, designers should be aware of this potential to improve their designs (Gurung et al., 2016)

According to Building Energy Efficiency Technical Guideline for Passive Design (2016), although there are many existing external shading device options in the market as a solution for energy efficient buildings, their optimisation and their combinations with internal shadings can be more beneficial. Therefore, their features and their contributions should be considered carefully.

2.2.1.1. External shading devices

The types of external shading devices can be described as horizontal, vertical and egg create. The important thing in the usage of them is that application of them in order to avoid the heat gain in the summer period, the winter period should be considered according to hot or cold climates separately as well (CND,2015).

2.2.1.1.1. Horizontal shading devices

Horizontal shading devices are used to block the summer sun but allow entering the winter sun inside to warm the building (Gurung et al., 2016) (See in Figure 6). They are especially suitable for blocking southern exposure in the building. Additionally, horizontal shadings can be applied as different types (See in Figure 7) or combined with other shading devices and they can be integrated to roof easily in low-rise buildings on the south direction in order to reduce expenditures and create more aesthetical solutions(CND,2015). On the other hand, while designing horizontal shading devices, vertical offset from the top of the window and horizontal overlap issues should be considered carefully to make the shadings more effective (See in Figure 8).

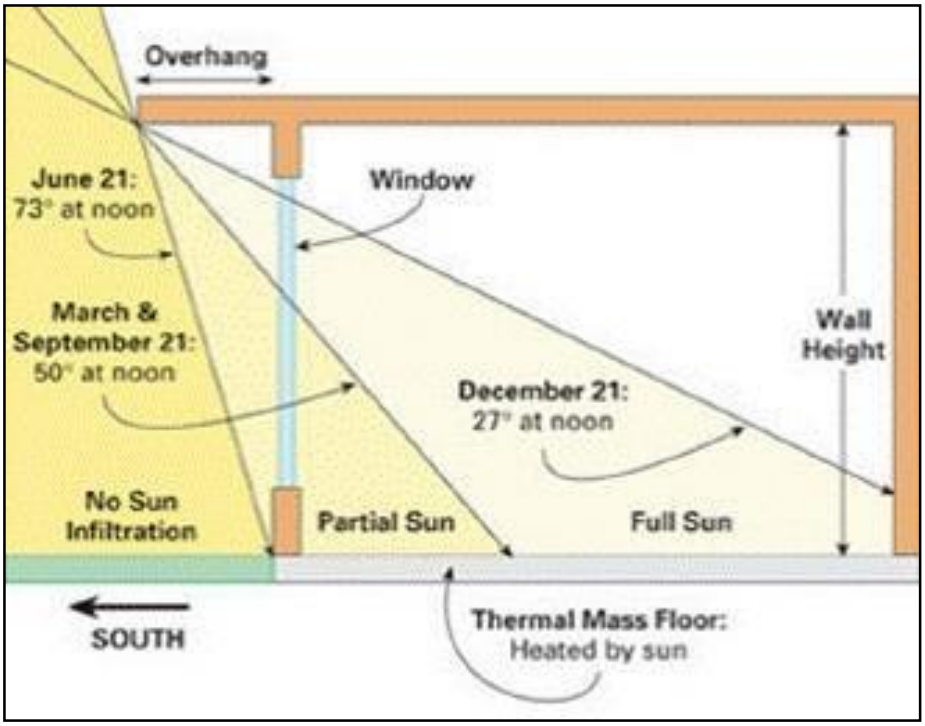


Figure 6: Principle of horizontal shading devices (WBDG, 2017)

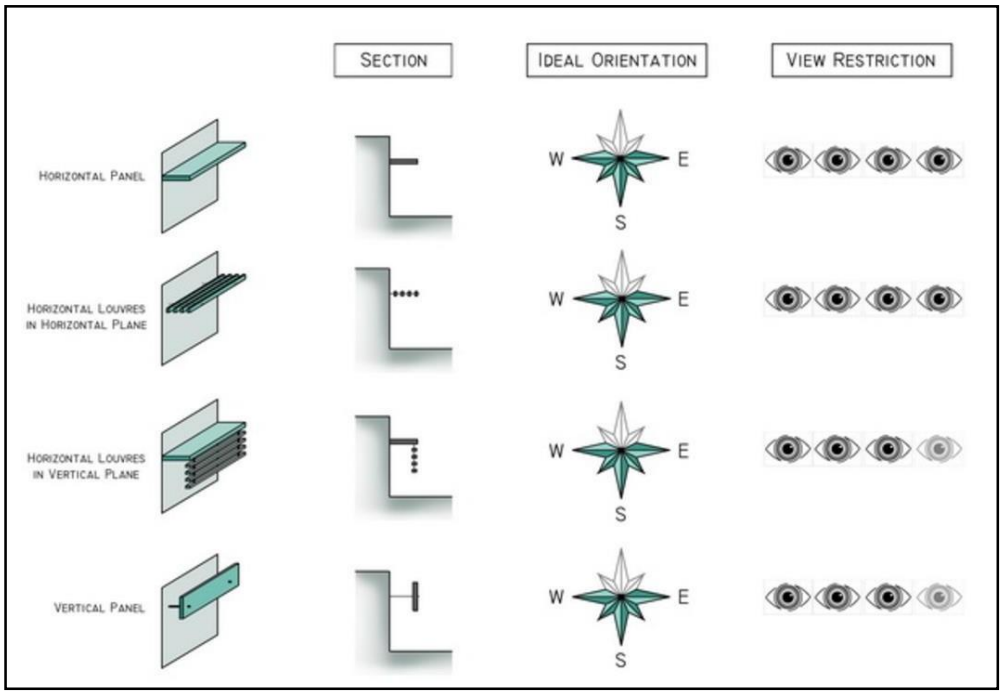


Figure 7: Basic typology of horizontal shading devices (CND, 2015)

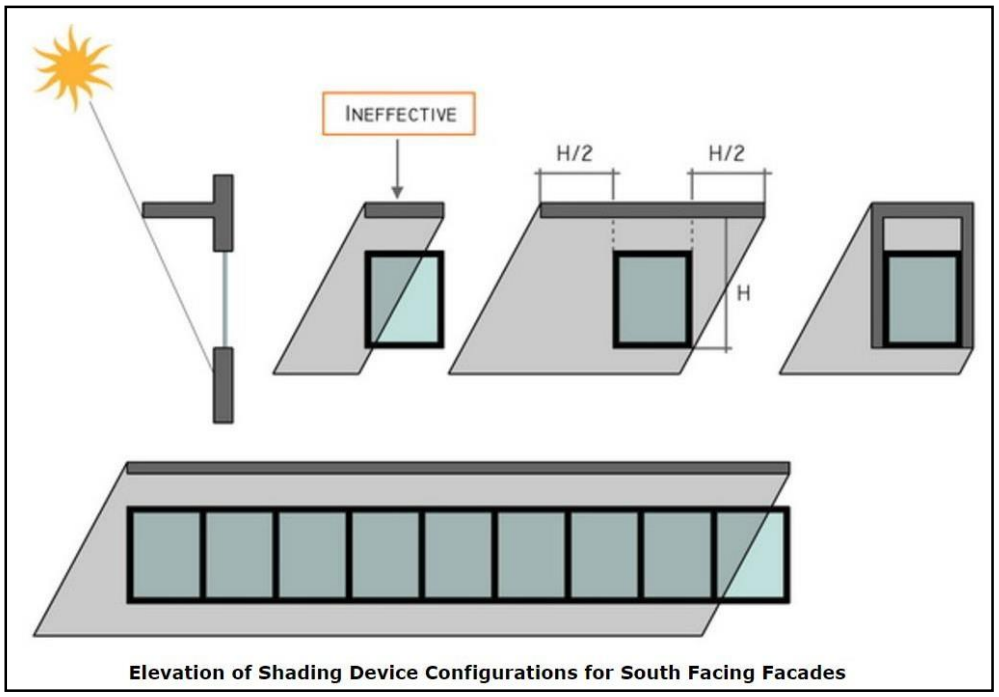


Figure 8: Configuration of horizontal shading devices (CND, 2015)

2.2.1.1.2. Vertical shading devices

Vertical shading devices can become varied depending on the direction and the purpose (See in Figure 9). They display a very good performance South-eastern and South-western direction in reducing solar gain. In addition to their solar gain reduction in the summer period, they are very beneficial by acting as a windbreak in winter period. In order to avoid heating, the building should be formed by considering the windows on suitable direction with suitable shading during the design process. While designing the vertical shading devices, application them from right to left should be supported by putting extra fins in front of the window in order to enhance the shadings efficiency (See in Figure 10). As can be seen in Figure 11, as long as the distance between fins decreases, solar penetration accordingly solar gain decreases as well (CND, 2015).

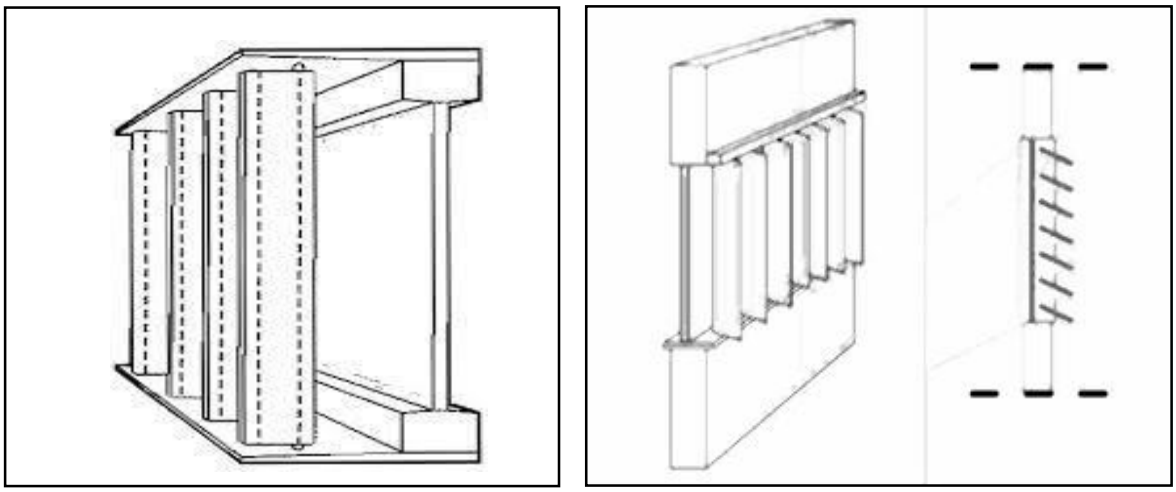


Figure 9: Vertical fins and slanted vertical fins (Gurung et al.,2016)

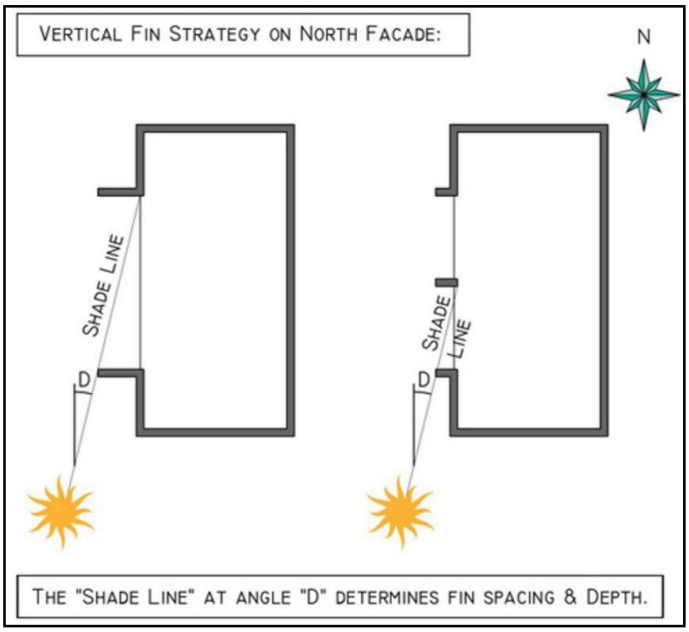


Figure 10: Vertical fin strategy on North façade (CND, 2015)

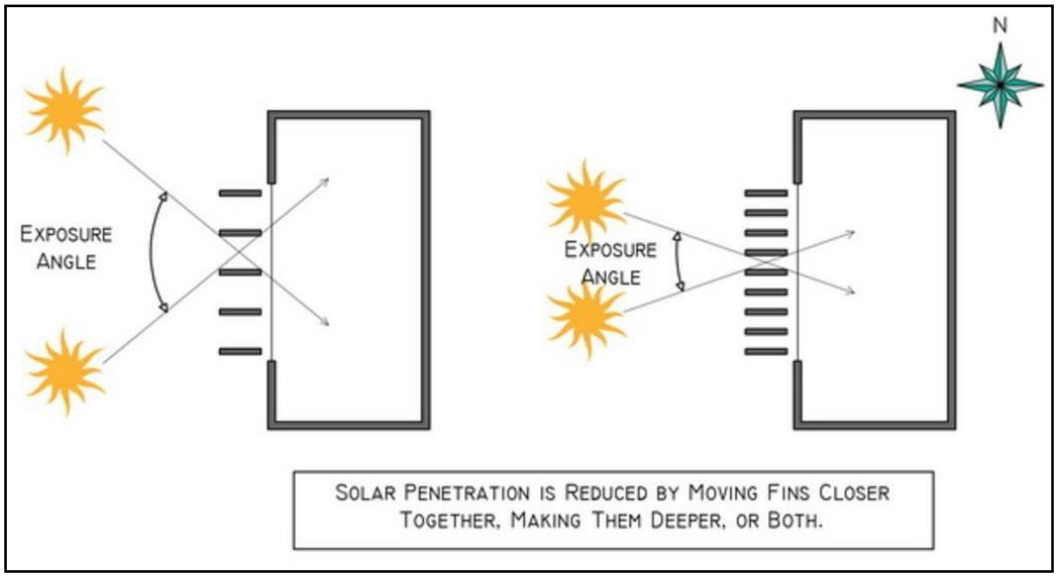


Figure 11: Reduction in solar penetration (CND, 2015)

2.2.1.1.3. Egg create shading devices

Egg create shading devices consist of vertical and horizontal shading devices combinations. These shadings are commonly used in hot climate regions due to their high shading abilities (Gurung et al., 2016)

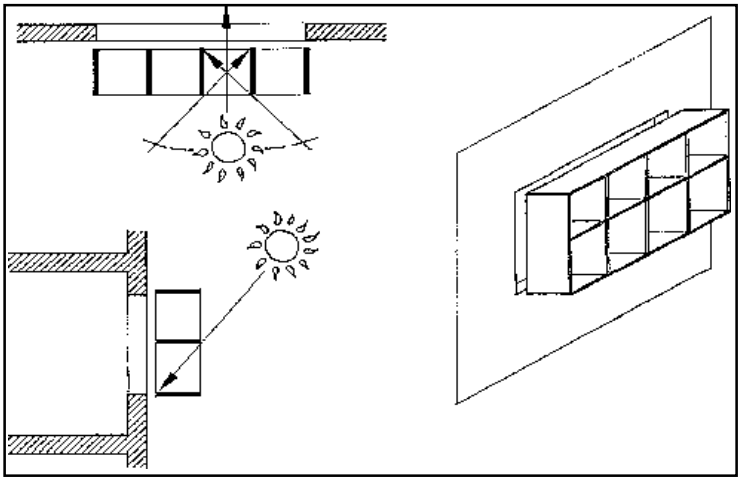


Figure 12: Principle of egg create shading devices (Gurung et al., 2016)

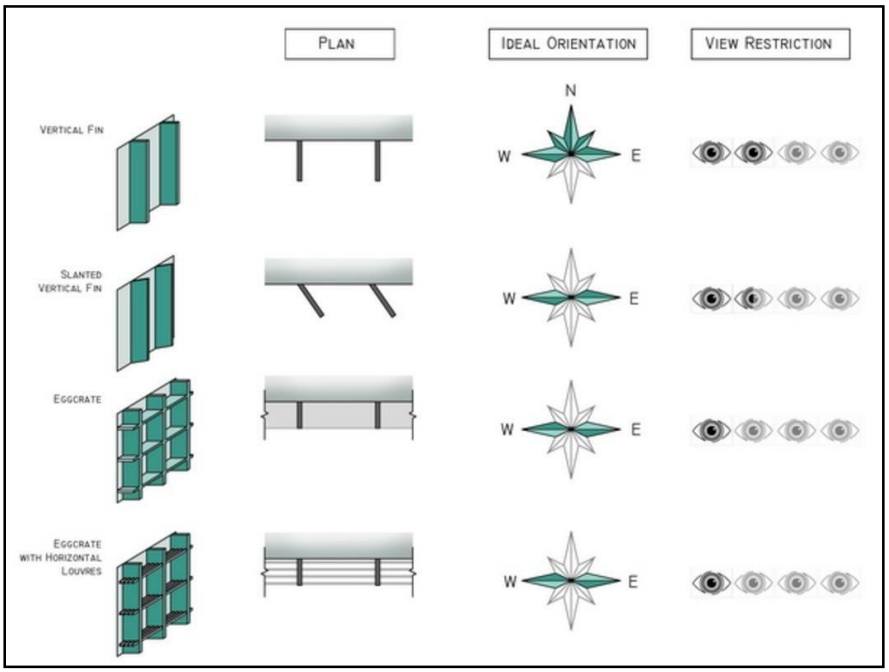


Figure 13: Basic typology of vertical and egg create shading devices (CND, 2015)

2.2.1.1.4. The performance of external shading devices depending on the direction

Each orientation gets a different amount of sunlight, correspondingly their precautions on each direction need to differ. In order to design effective solar shading devices, first of all, it is necessary to understand solar geometry and the solar effect on each direction.

The north orientation does not need solar shading as a priority because the sun penetration is not seen in the early morning and late evening except for summer months. Due to too low sun angle, horizontal shadings will not be beneficial and sunlight can enter easily. The best way to block sunlight from north orientation is a limitation of fenestration as much as possible, so there will be too little solar gain not to cause a problem for overheating. If fenestration is necessary in terms of daylighting, highly efficient glazing should be selected to protect it from overheating.

Opposite of the north, solar control is the easiest in the south direction with horizontal shading devices whose projection dimensions are designed according to a formula related to the height of the window and solar angle. Because of the sun angle, these shadings are convenient to this orientation by reducing sun penetration in summer and allowing the light access in the winter period (See in Figure 14).

Moreover, shading the east and west elevations are too difficult because of the low sun angle in the morning and afternoon that makes horizontal shadings impossible (See in Figure 15) (CND, 2015).

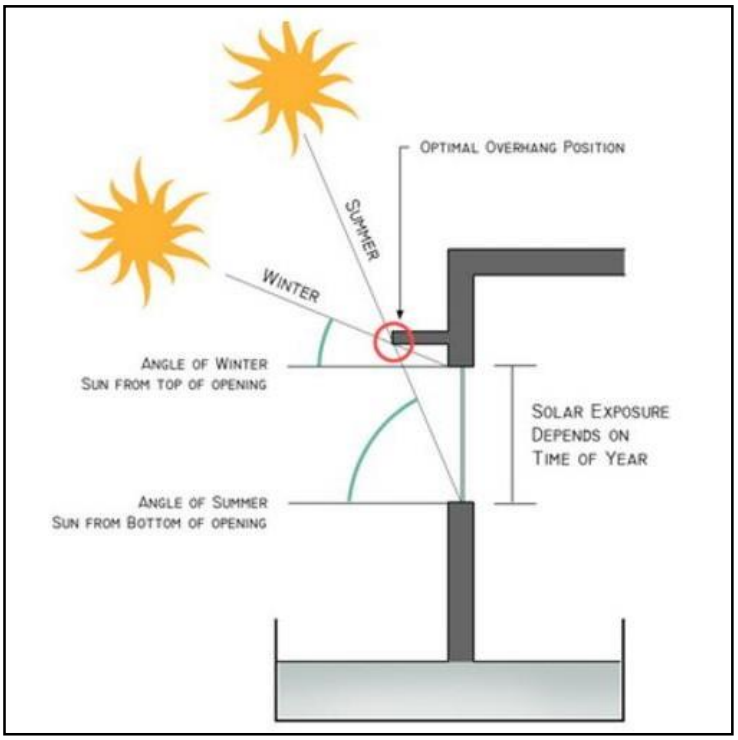


Figure 14: Basic shading strategy for South direction (CND, 2015)

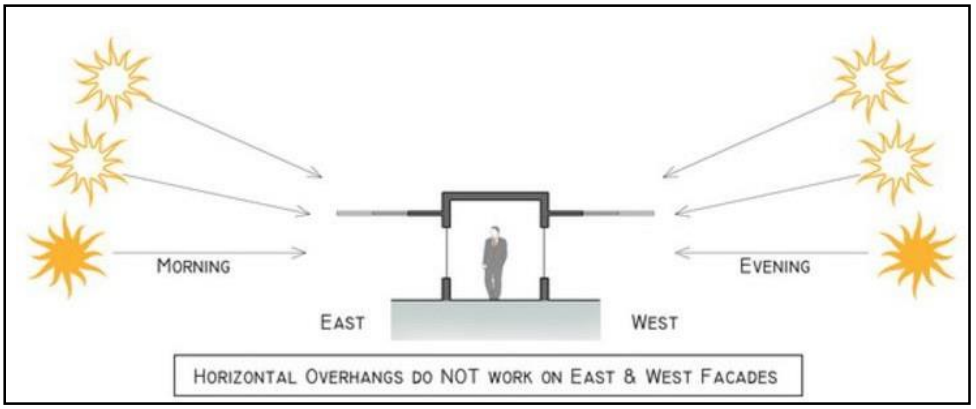


Figure 15: Basic shading strategy for East and West (CND, 2015)

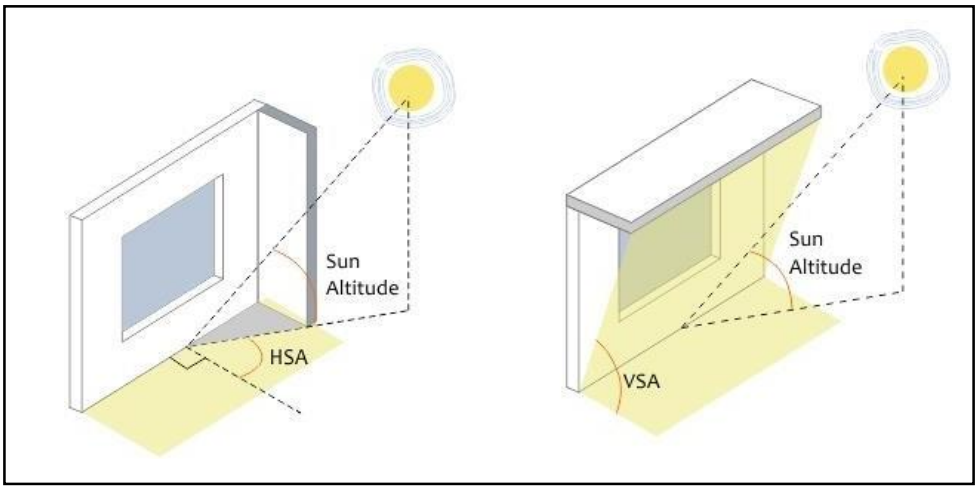


Figure 16: Horizontal shadow angle (HAS) and vertical shadow angle(VSA) (NZEB,2016)

According to NZEB (2016), external shading devices should be applied to the building by considering the direction of the window and the location of the building. Also, which type of external shading device usage is necessary and the correct angle should be decided depending on the overheating period. Furthermore, horizontal shadow angle and vertical shadow angle (See in Figure 16) are used to design external shading devices and these are related to the sun angle and building location directly.

As a general rule, vertical shading devices should be applied to the east and west direction of the building in order to protect the building from the high amount of solar gain. On the contrary, horizontal shading devices should be used on north and south direction by considering the sun path. Additionally, egg create shading devices, which are combinations of horizontal and vertical devices, have a chance to be applied in all directions of the building. As can be seen in Figure 17, it is possible to compare all shading devices in terms of physical structure, VSA and HSA.

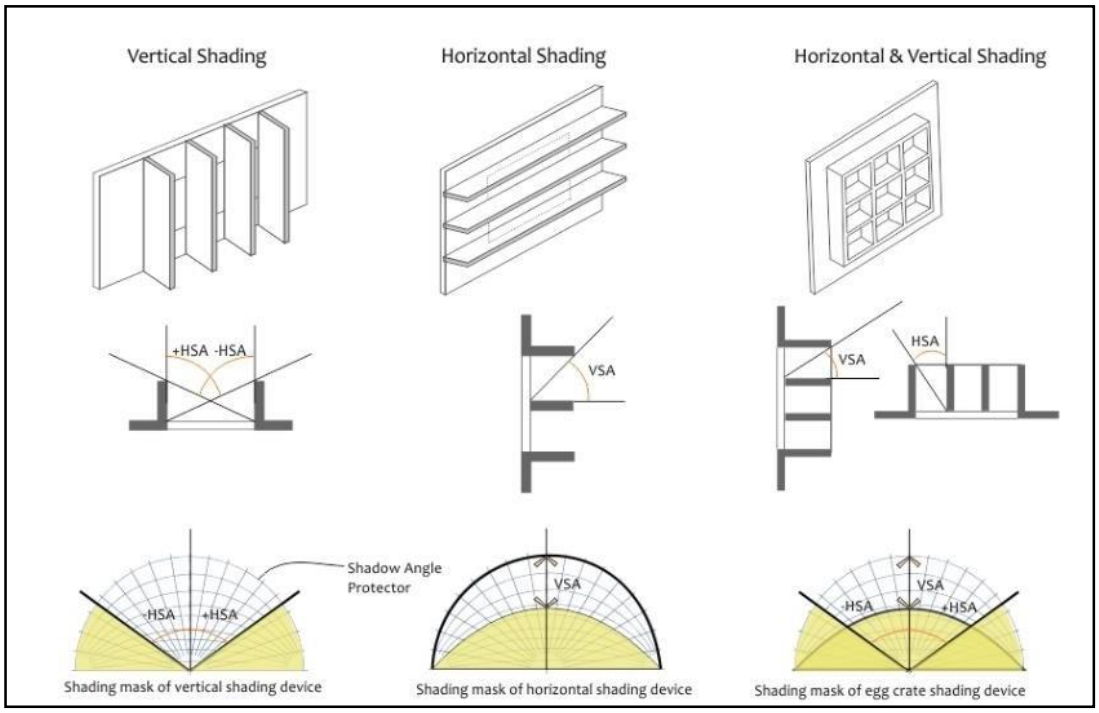


Figure 17: The comparison of external shading types (NZEB, 2016)

2.2.1.2. Internal shading devices

Glaring which is an important problem in buildings arise from the solar radiation but fortunately, the problem can be limited by internal shading devices which are adjustable and give the occupants an opportunity to arrange the amount of sun penetration. Thermal and visual comfort oblige to keep the inside temperature constant at the comfort level. In this case, internal shading devices can be a possible solution to reduce the amount of solar gain. Even if highly efficient glazing is used in the windows, internal shadings whose most commons are curtains, venetian, vertical and roller blinds are usually preferred in the buildings (See them in Figure 18 and 19). Although all internal shading devices perform worse than external shadings against to the sunlight, occupants should use them as a way to reduce solar heat infiltration. Also, they should be designed to be durable as far as possible and preferably they should be made of recycling materials (Greenglobes, 2017).



Figure 18: Curtain and venetian blind examples respectively (Gurung et al., 2016)



Figure 19: Vertical and roller blind examples respectively (Gurung et al., 2016)

2.2.1.3. The difference between external and internal shading devices

Both internal and external shading devices have the ability to reduce solar gain but generally, external shading performance is higher than internal shading because they block solar radiation before sun penetration (See in Figure 20). Conversely, when an internal shading is used such as blind or curtain, coming sun is reflected subsequent to hitting the shading devices and depending on the shading's reflectivity and colour, the rest is absorbed by the shading device warming it up. Therefore, a considerable part of heating shading device causes a temperature rise in the room. Nonetheless, if the right internal shading is selected, it performs well as much as external shading devices (Building, 2016).

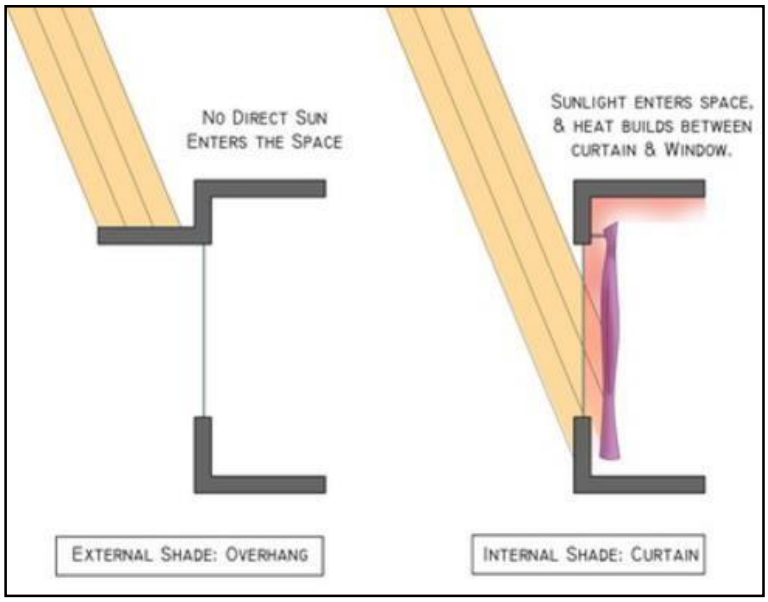


Figure 20: External and internal shading working principles (CND, 2015)

3. Methodology

3.1. Outline of the methodology

The aim of the research is to solve the problems about high air temperature and poor indoor air quality of the office buildings in Izmir by benefiting from external shading devices in order to improve occupant working conditions. For this purpose, some quantitative analysis methods were developed to reduce energy loads and improve occupant satisfaction at the same time and they will be explained step by step in this section.

For the purpose of monitoring the air temperature, illuminance level, thermal and visual environment and comparing to the improvements with the base case, first of all a typical office building plan (See in Figure 14) was found from one of Turkish construction company in DWG format and then, this drawing was used to create a building model in Designbuilder software, which is a whole building energy simulation tool and widely accepted by the building energy simulation community to perform energy and daylighting simulations, and the model was used to perform simulations of different types of external shading devices with different factors on different orientations in order to analyse their cooling and lighting energy flows while maintaining the convenient indoor conditions for offices. Then, the results obtained from analyses were evaluated by comparing with each other, the best ones were selected in terms of energy consumption and at the end of this process, the optimum option was created by combining all best options.

3.2. The Energy Simulation Software Tools

3.2.1. Introduction to energy simulation software tools

According to Sousa (2016), approximately a third of whole energy consumption of the buildings is used for improving thermal conditions and lighting level. For this reason, dynamic modeling simulation software is developed in order to enable users to analyze energy consumption of the buildings, decrease the energy consumption and accordingly their cost. Also, they are very beneficial to determine the convenient size and types of the HVAC systems.

Currently, during the initial design stage, architects need some helpful tools to consider specific preferences such as heating, lighting or cooling. Therefore, they use energy simulation software tools to estimate following indoor air quality, amount of energy consumption and its cost. While reducing the amount of energy consumed, their main aim is to reduce indoor temperatures to comfort level and improve ventilation and lighting levels correspondingly.

3.2.2. Steps to Perform in a Building Energy Simulation

There are various energy simulation software tools available in the market and day by day the number of the tools has increased with the need of calculating energy requirements of the buildings. Generally, all energy simulation software tools require following three steps to simulate the buildings as creating the building, building simulation and analysis of the results.

3.2.2.1. First step- Creation of a building

As the first step, it is necessary to create the building drawings in order to monitor its performance in the following stages. Drawing can be done in the energy simulation software tool by using the coordinates as references or it can be drawn in another software such as AutoCAD or Google Sketch Up and it can be imported to the energy simulation software tool. In this stage, the specification of construction components such as building geometry, structural properties, dimensions, materials and selected HVAC systems has importance to develop the model and get exact results (Sousa, 2016).

3.2.2.2. Second step- Building simulation

According to Sousa (2016), during this stage, the specification of the variables which will be considered in the simulations of the building has a significant role on the following simulation stage and analyzing the results obtained from software running. Indoor air quality of the building and occupant satisfaction change depending on the building's purpose of use, human activities, indoor equipment and occupancy hours. Therefore, it is necessary to identify these parameters to get specific results for the relevant building.

3.2.2.3. Third step- Analysis of the results

After the building simulation process, first of all, checking whether there is an error or not in the variable set is very important. Sometimes, warning messages can be seen in the final report of the results including all relevant variable result information, therefore the results should be analyzed very carefully.

At the end of the process, physical features, energy and HVAC systems, human comfort level and sunlight amount with shading effects should be considered. Generally, there are four factors which have a great importance on the final results and they are ranged as building organizations, physical factors, weather conditions related to the location and the purpose of the building. Additionally, physical feature of the materials with their components and their energy performance should be considered as well (Sousa, 2016).

3.2.3. The reason for preference Energy Plus and Designbuilder

As can be seen in Figure 21 about the energy simulation software tool comparison with each other, there is a great variety of simulation tools such as Energy Plus, ESP-r, IDA ICE, IES VE and TRNSYS. Despite the fact that each software tool has a different level of complexity and different specializations, Energyplus is preferred mostly according to user perspective and their final purposes. Although Energy plus aims to simulate models for energy flows like heating, cooling and lighting, it has not any visual interface to enable the users to shape their building. Therefore, Designbuilder software tool is used with Energy Plus coordinately to allow the people to see and draw their building (Sousa, 2016). During the research, Energy Plus and Designbuilder combination were used to simulate model because of being familiar with them, having some experiences on these software tools and easiness of Designbuilder to enable users to connect with AutoCAD software tool to import and export files, unlike some energy simulation software tools.

	Energy Plus	ESP-r	IDA ICE	IES	TRNSYS
Simulation Solution					
Simulation of loads, systems and solutions	X	X	X	X	X
Iterative solution of nonlinear systems	X	X	X	X	X
Duration of Time Calculation					
Variable time intervals per zone for interaction of the HVAC system	X	X			
Simultaneous selection of building systems and user		X	X	X	X
Dynamic variables based in transient solutions	X	X	X		
Complete Geometric Description					
Walls, roofs and floors	X	X	X	X	X
Windows, skylights, doors and external coatings	X	X	X	X	X
Polygons with many faces	X	X	X	X	
Imports of building from CAD programs	X	X	X	X	X
Export Geometry of Buildings for CAD software	X	X	X		
Import / Export of simulation models of programs	X	X	X	X	
Calculation of thermal balance	X	X	X	X	X
Absorption / release of moisture from the building materials	X		X	X	X
Internal thermal mass	X	X	X	X	X
Human thermal comfort	X	X	X	X	X
Solar Analysis	X				X
Analysis of Isolation	X	X	X	X	X
Advanced fenestration	X	X	X	X	X
Calculations of the building in general	X	X		X	X
Surface temperatures of zones	X	X	X	X	X
Airflow through the windows	X	X		X	X
Driving surfaces	X	X	X	X	X
Heat transfer from the soil	X	X	X	X	X
Thermophysical variable			X		
Daylighting and lighting controls	X	X	X	X	
Infiltration of a zone	X	X	X	X	X
Automatic calculation of coefficients of wind pressure				X	
Natural Ventilation	X	X	X		X
Natural and mechanical ventilation				X	X
Control open of windows for natural ventilation	X	X	X		X
Air leaks in multiple zones	X	X	X		X
Renewable Energy Systems					
Solar Energy	X	X		X	X
Trombe Wall	X	X	X	X	X
Photovoltaic panels	X	X		X	X
Hydrogen Systems		X			X
Wind Energy		X			X
Electrical Systems and Equipment					
Energy Production through R.E.	X	X			X
Distribution and management of electric power loads	X	X			X
Electricity generators	X				X
Network connection	X	X			X
HVAC Systems					
HVAC idealized	X	X	X	X	X
Possible configuration of HVAC systems	X	X	X	X	X
Repetitions cycle air	X	X	X	X	X
distribution systems	X	X	X	X	X
Modeling CO_2			X	X	X
Each distribution of air per area	X	X	X	X	X
Forced air unit per zone	X	X	X	X	X
Equipment Unit	X	X		X	X

Figure 21: Comparison of various Simulation Software tools (Sousa, 2016)

3.3. Step 1: Literature review

The first step in the research is reviewing the existing literature on the identified subject as a most convenient way to begin a research project for the purpose of avoiding waste time with repetitions what the other researchers have done. Therefore, first of all, a literature review was done about the external shading devices but in order to understand this issue correctly, all shading devices and their working principles with their differences, overheating and overheating analysis methods and essential conditions for occupant satisfaction in terms of thermal comfort and lighting were researched and the information obtained from different sources such as books, articles, academic journals, journal articles and websites was presented in literature review section of the dissertation. This knowledge acquisition assisted to identify important variables, analyze the results easily and comment on the diversity of the results in further steps.

3.4. Step 2: Creation of the building

3.4.1. Import the drawing from Autocad into Designbuilder

In order to make a model in Designbuilder, initially, it is necessary to import the drawing from Autocad into Designbuilder, whereas Designbuilder software only allows importing 2d floor plan files in Autocad or other CAD programs as DXF format. Therefore, the DWG file in Autocad was saved as DXF and then on the purpose of importing the file into Designbuilder, Files > Import > Import DXF data menu commands were followed to get the office plans (See in Figure 22 and 23).

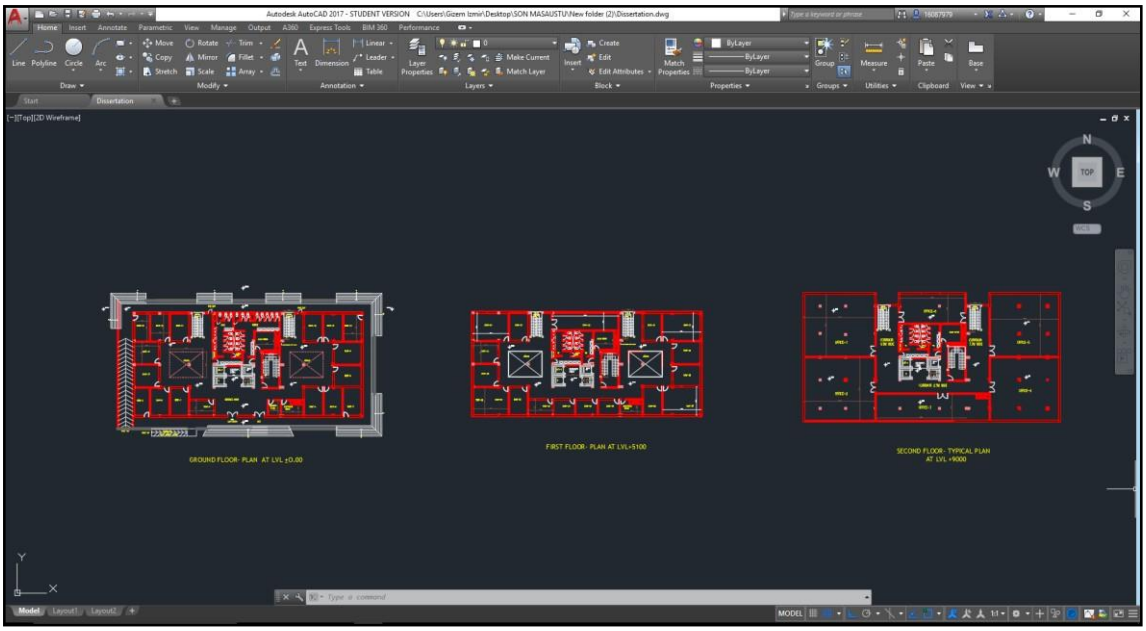


Figure 22: Exported file from AutoCAD

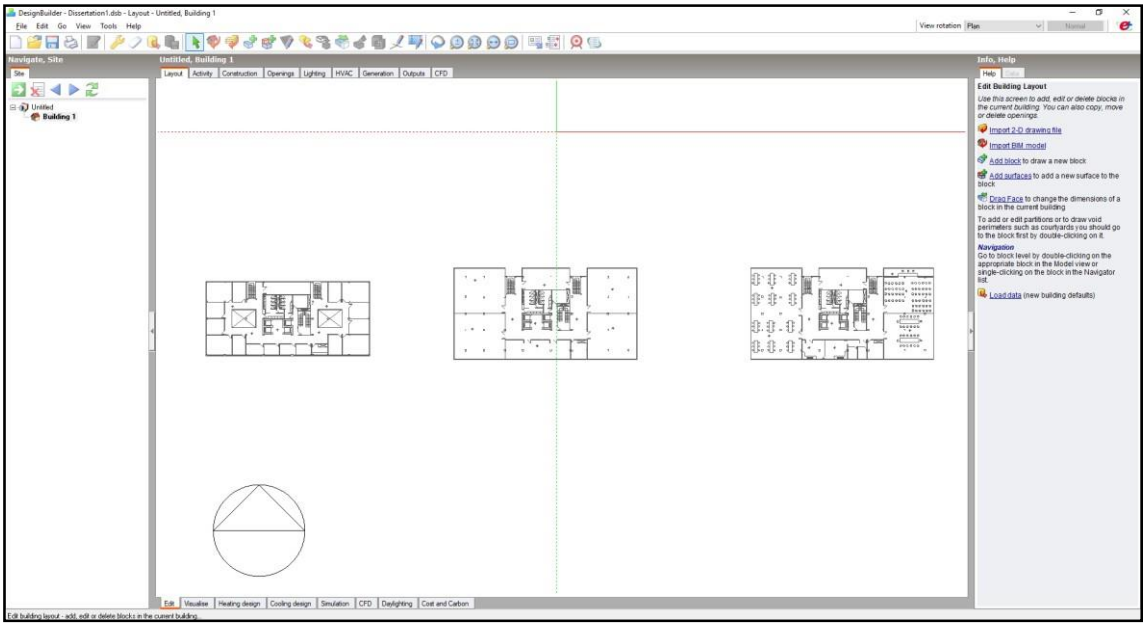


Figure 23: Imported file into Designbuilder

3.4.2. Modelling the building in Designbuilder

Before creating the whole building, the floor plan of the building which would be analyzed was drawn by following the instructions suggested by Designbuilder tutorial videos on their website (Designbuilder, 2017).

3.4.2.1. Base case office building's features

The floor plan was selected as a typical open office plan example in Turkey whose circulation areas, toilets and storage are located in the center of the building surrounded by open plan offices. The base case building has 10 floors whose the ground and first floors are narrower than the others as 46-meter-long and 21.2-meter-wide rectangular and the other floors covering the exact floor plan which will be analyzed are measured as 52-meter-long and 26-meter-wide. In the back of the building, after 14.5 meters from the corners, there are some indentations as 5-meter-long and 2.40-meter-depth. Although the ground floor height is designed as 5 meters, the other floors' height is specified as 3 meters. Also, when focused the floor which was analyzed, it has 8 windows on the north and south direction and 4 windows on the east and west as 3.10-meter-long and 1.5-meter-high and distance between windows are 2.6 meters.

3.4.2.2. Drawing the floor plan

3.4.2.2.1. Drawing the base perimeter of the building

After the importation of the drawing from AutoCAD, in order to create a new block, building level was selected and Add new block tool was clicked (See in Figure 24). The block is created by drawing the base perimeter of the block and the drawing was constituted by following the imported file. As can be seen in Figure 25 in drawing options, the building block is selected as block type because this type is used for drawing walls, floor slabs and roofs. The form was selected as extruded because after drawing the perimeter of the block (See in Figure 26), it provides to extrude the plan automatically by the identified height in the drawing options.



Figure 24: Add new block button

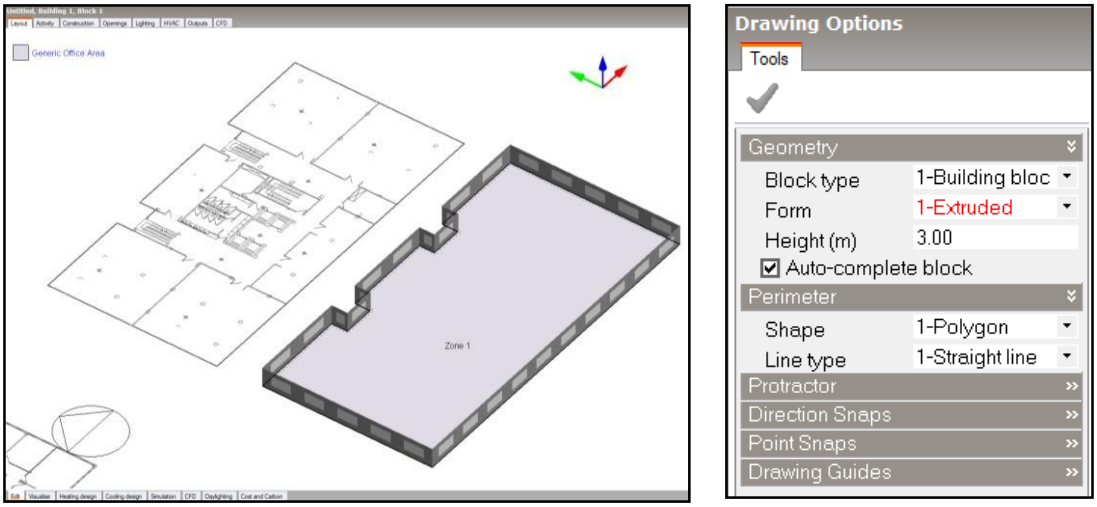


Figure 25: Drawing options of the walls

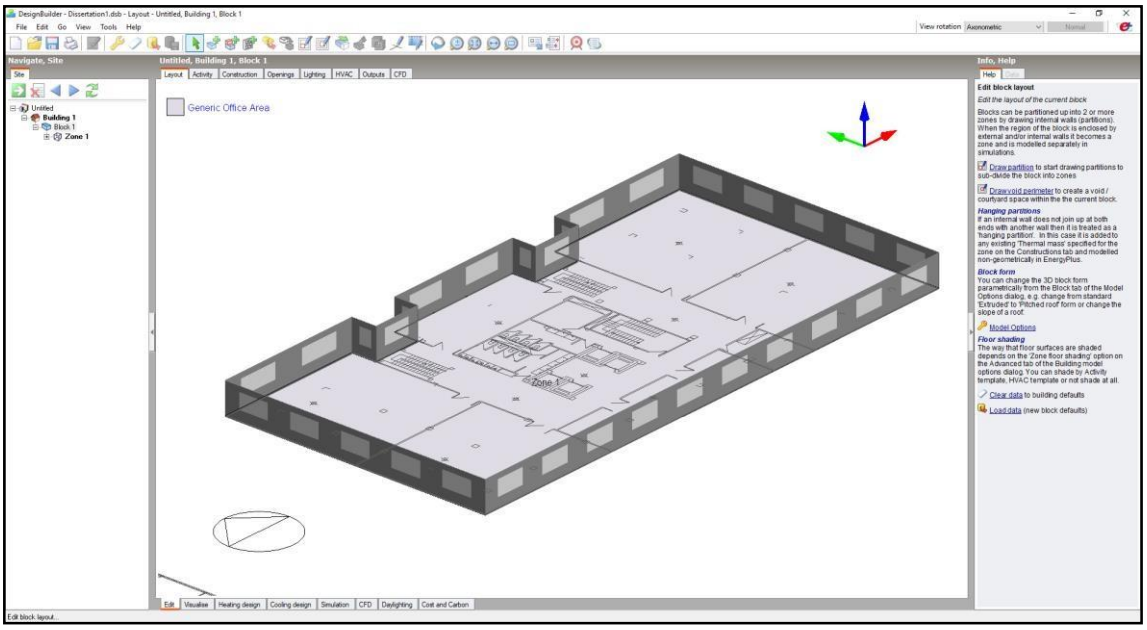


Figure 26: Drawing the base perimeter of the block

3.4.2.2.2. Drawing the internal partitions of the building

After drawing the base perimeter of the block, automatically compatible windows with drawn building appear. These windows were deleted and then determined windows were put after drawing internal partitions which use walls to divide blocks into different zones. Internal partitions are used in only occupied spaces and they represent all actual internal walls' layers. They are created in block level by tracing over the floor plan partition data and in order to create internal partitions, Draw partition tool (See in Figure 27) was clicked and partitions were placed according to imported file data by snapping to external block walls. Also, drawing option window (See in Figure 28) was used to define the thicknesses of partitions. Partitions are important to divide zones within the block, therefore a different type of spaces with different occupant hours, materials and functions can be defined. As soon as placing partitions to divide zones, the spaces are re-zoned automatically. For this reason, all zones were renamed and their properties were changed in Activity tab according to the function of the space.



Figure 27: Draw partition tool for internal partitions

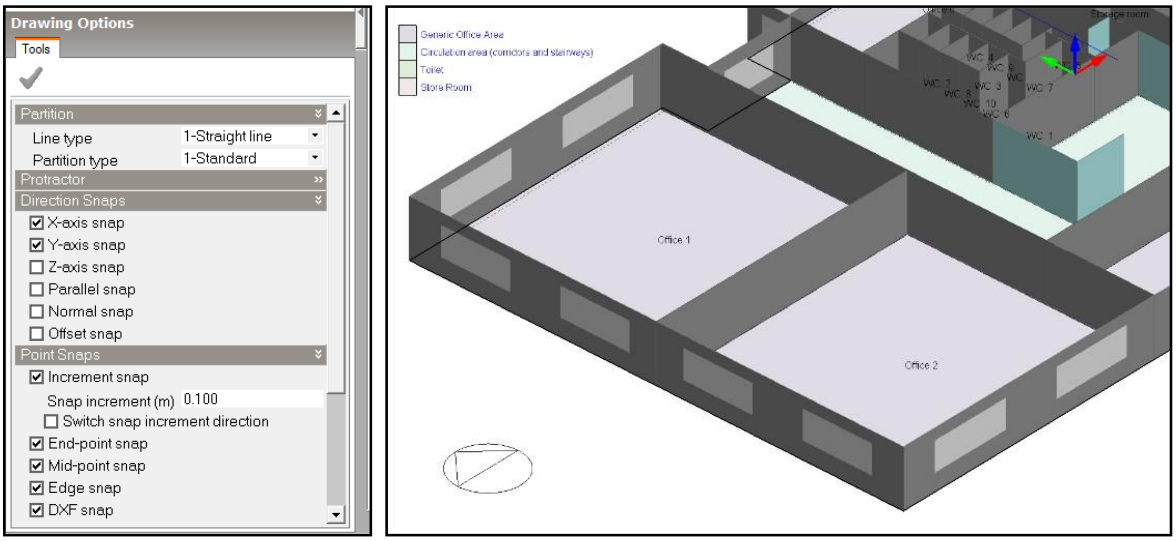


Figure 28: Zoning with partition walls and drawing options

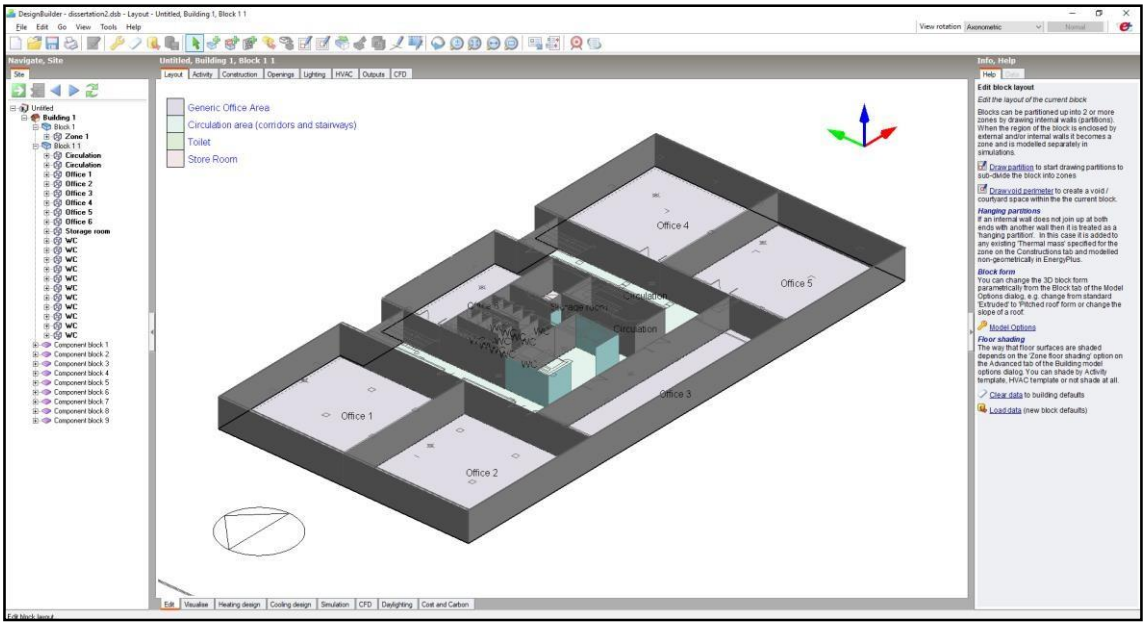


Figure 29: Drawing the internal partitions of the block

3.4.2.2.3. Drawing the windows of the building



Figure 30: Draw partition tool

As stated previously, after the creation of the base perimeter of a block, automatically windows appear and if required, they can be kept, modified or deleted. In this case, all windows were deleted and predetermined windows were applied. On the purpose of window application, draw window command was selected (See in Figure 30) and the window position was defined related to an origin by first moving the mouse cursor as can be seen in Figure 31.

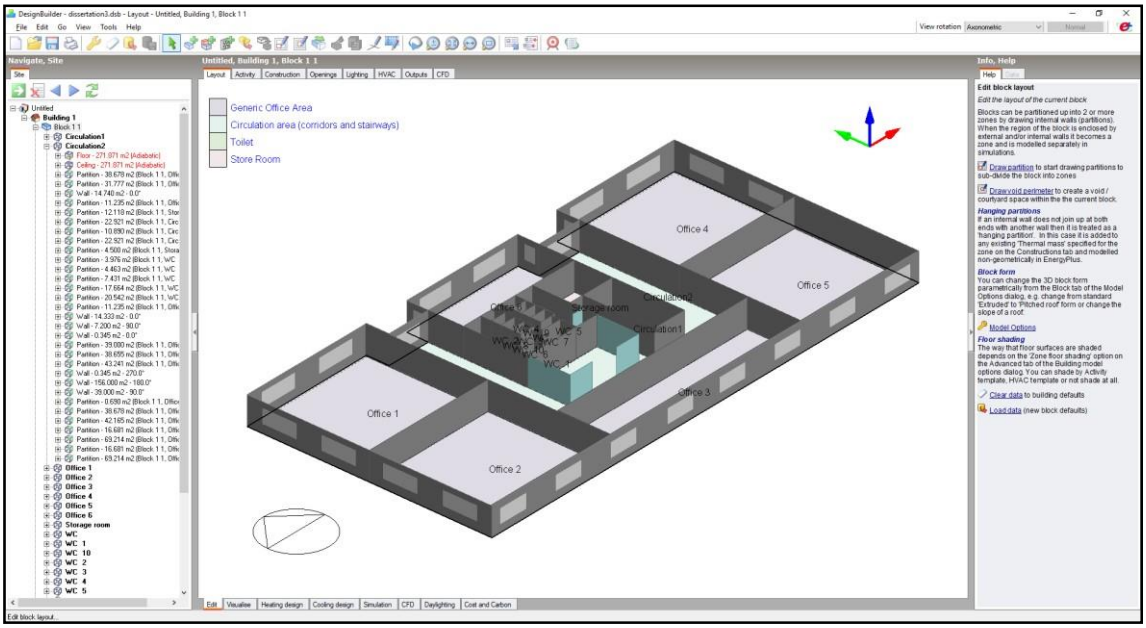


Figure 31: Adding new windows in the block

3.4.2.2.4. Data input about the location of the building

In order to select a location and assign weather data, Location tab on the site level was clicked. From here, Izmir city was selected under the country of Turkey (See Figure 32). Therefore, Turkey's climate conditions would apply to the simulations after the data input about the location of the building.

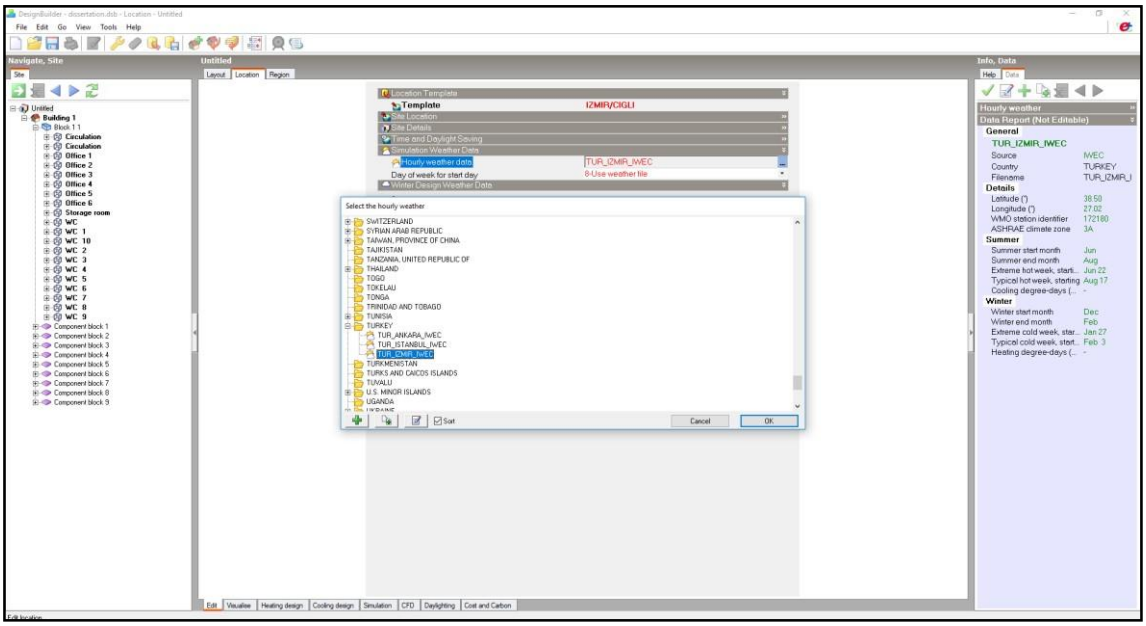


Figure 32: Selection of location

3.4.2.2.5. Data files, template and components

In order to manage the building components, model data tabs were changed on the building level (See in Figure 25). In this study, construction template, glazing template and glazing type, lighting template were selected as best case defined by Designbuilder. On the other hand, activity template was selected as generic office area and occupancy

was defined as Office_OpenOff_Occ in order to calculate only occupied hours. Also, infiltration rate was selected as 0.05 ac/h in 24 hours duration and HVAC template was selected as Fan Coil Unit (4-Pipe), Air-cooled Chiller. Otherwise, mechanical ventilation, heating, cooling and DHW were selected as active during the occupancy hours. At the end of the process, the floor plan shown in Figure 33 was created.

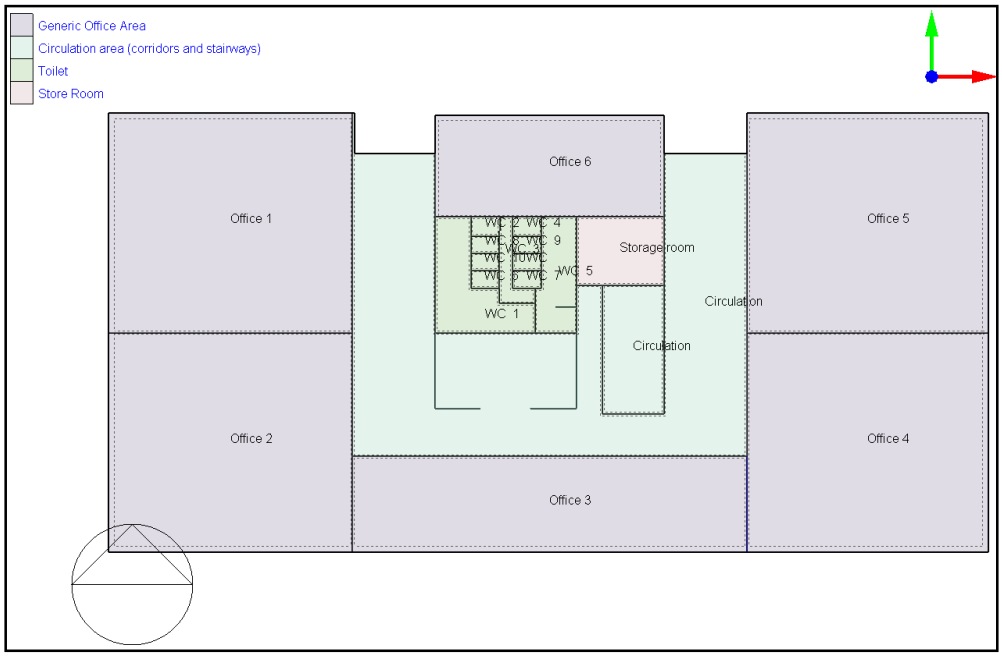


Figure 33: Typical office plan in Designbuilder

3.4.2.2.6. Creation of adiabatic blocks

After drawing the floor plan which would be analyzed, the other floors were created as adiabatic blocks (See in Figure 34). Adiabatic blocks are drawn in the same way as building blocks but the component block was selected in the drawing options' block type option (See in Figure 25). These blocks do not affect simulation results, therefore they are used as only reference blocks. After creating of adiabatic blocks, they were gathered with the analyzed floor before the simulation step (See in Figure 35).

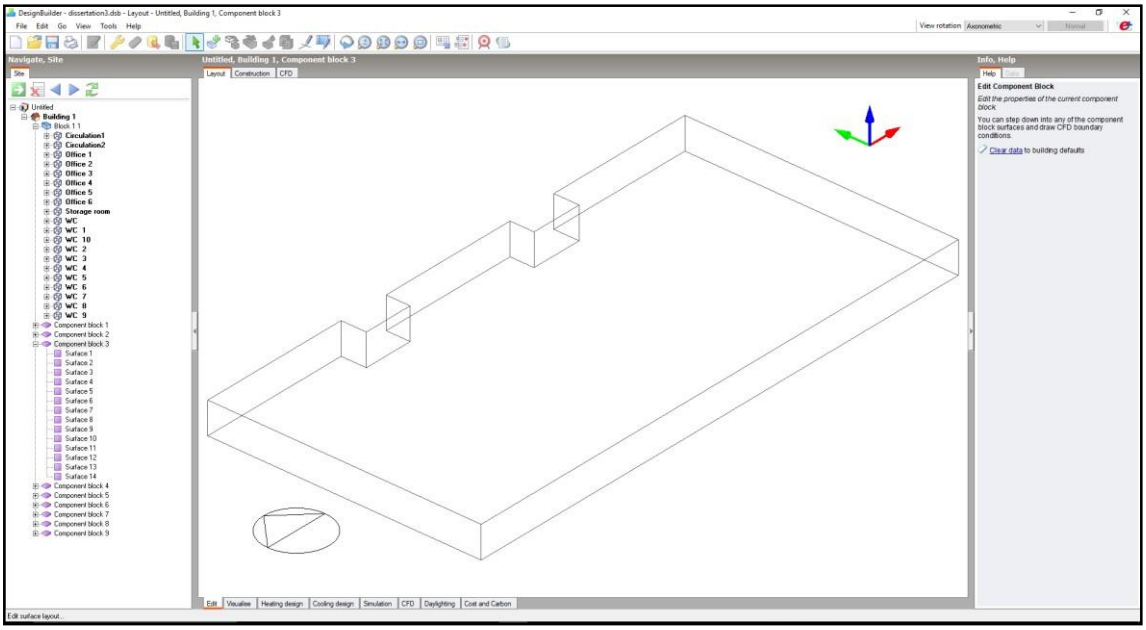


Figure 34: Drawing adiabatic blocks

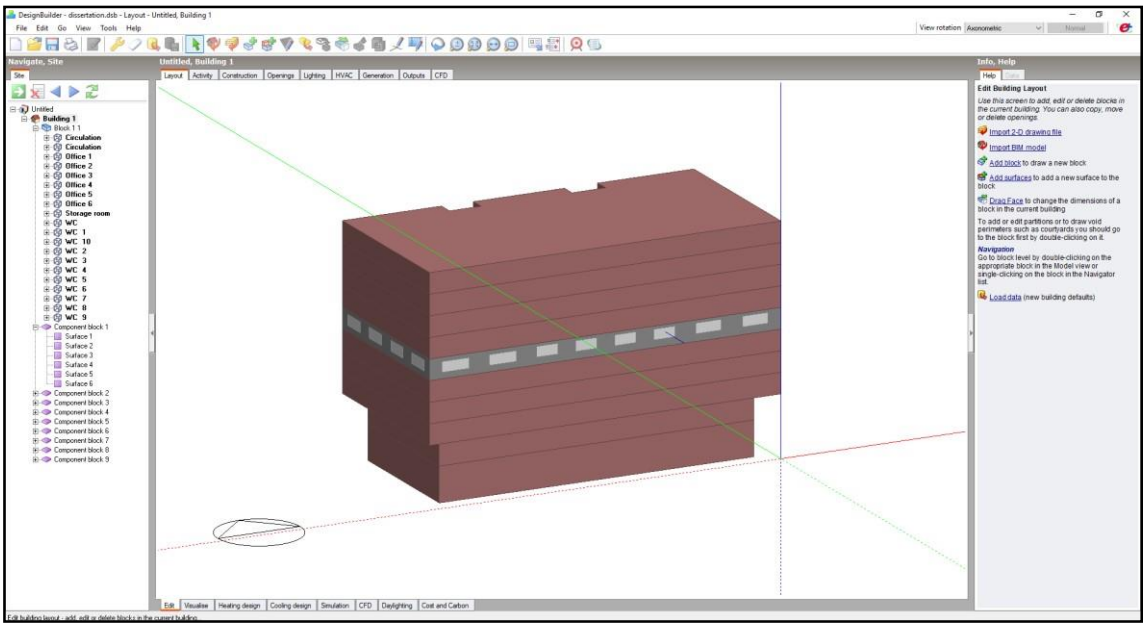


Figure 35: Modelled office building in Designbuilder

3.5. Step 3: Identification of variations

In order to evaluate the office building by simulating, it is necessary to identify which factor will be changed and which variables will be used before simulation step. For this purpose, external shading devices were divided into three types as overhang, louvre and sidefin and according to their properties, variables were identified and presented in Table 1. While three variables were selecting for overhang and sidefin shading devices, four main variables were predetermined for louvre shading devices in order to observe their performance on cooling and lighting loads. Figure 37 shows the structure of the shading device types which were analyzed. Otherwise, Figure 38 gives an opinion about these shading devices' working principles in order to increase understanding and the factors which were identified to comment about them.

External Shading Type 1	OVERHANG Variables	Type 1	Type 2	Type 3	Type 4
	Vertical offset from window(cm)	0	10	20	30
	Projection(m)	0.5	1	1.5	2
	Horizontal overlap(cm)	0	15	30	45
External Shading Type 2	LOUVRE Variables	Type 1	Type 2	Type 3	Type 4
	Vertical spacing(cm)	20	25	30	35
	Distance from window(cm)	10	20	30	40
	Blade depth(cm)	15	20	25	30
	Angle(°)	5	15	25	35
External Shading Type 3	SIDEFIN Variables	Type 1	Type 2	Type 3	Type 4
	Horizontal offset from window(cm)	0	10	20	30
	Projection(cm)	30	40	50	60
	Top and bottom overlap(cm)	0	10	20	30

Table 1: Identified variables for simulation

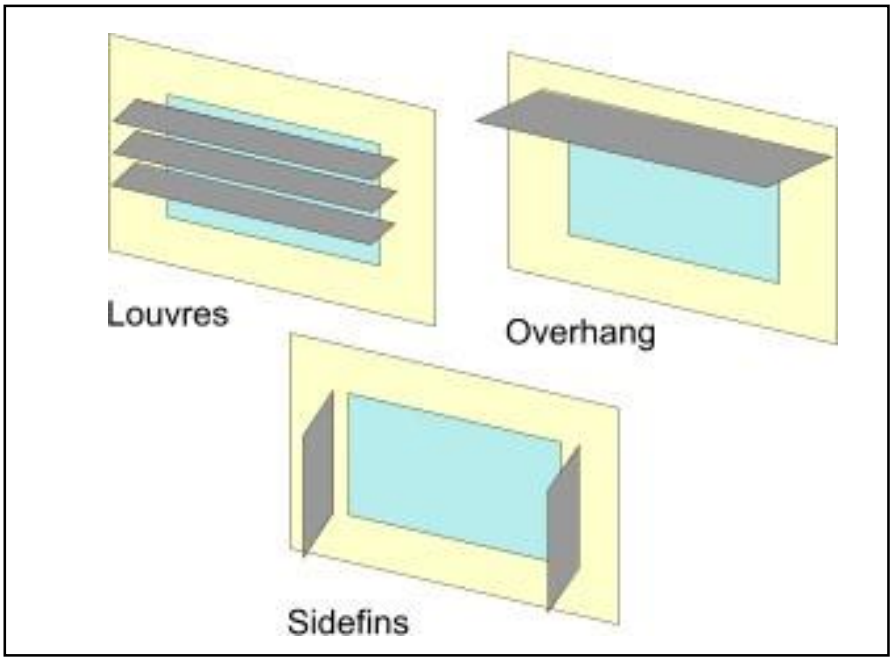


Figure 36: Descriptions of external shading types

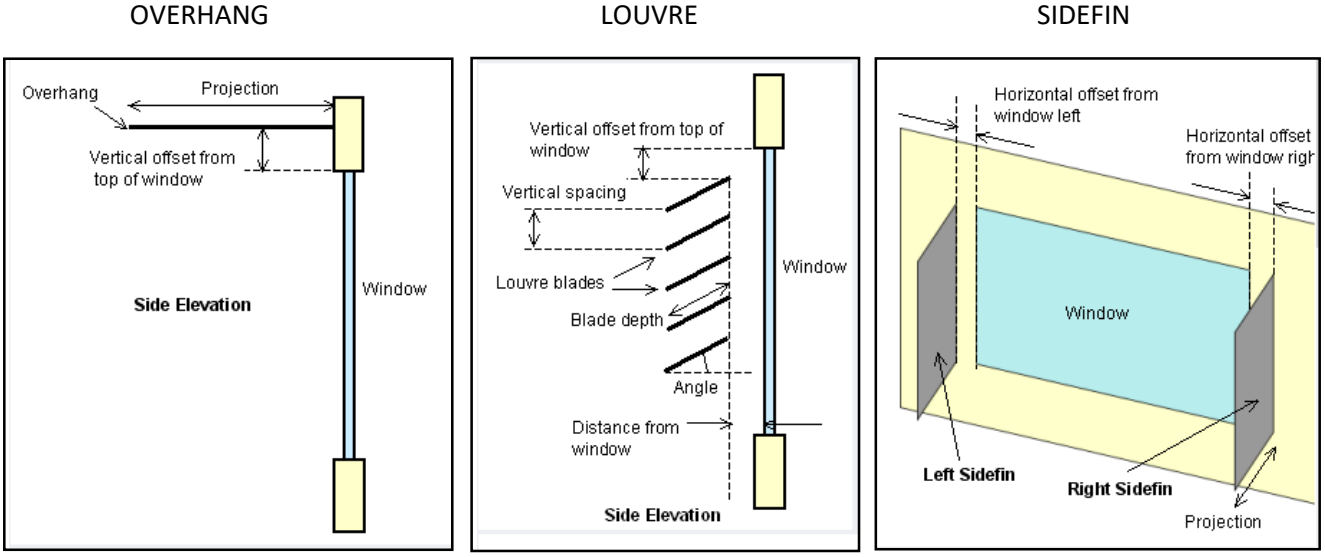


Figure 37: Working principles of predetermined variables

3.6. Step 4: Building simulation in Designbuilder

In the simulation step, the drawn floor plan was simulated by changing all variables for each direction (See in Figure 39). For instance, in order to understand the effect of projection factor on overhang's contribution to cooling and lighting load, overhangs whose projection values were 0.5, 1, 1.5, 2 meters were applied to the windows on different directions separately. In this case, both orientation changes and projection value changes were evaluated, therefore the effect of projection value became interpretable. At the end of the process, each variable was simulated on each direction in order to get comparable results.

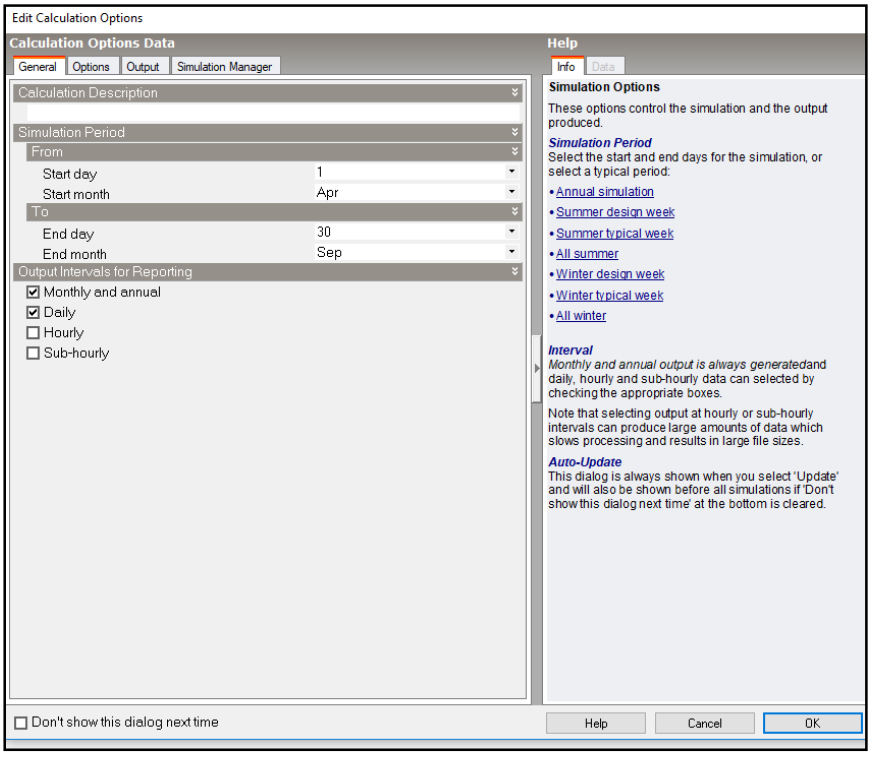


Figure 38: Simulation step in Designbuilder

Thanks to Designbuilder, it is possible to understand how much energy is consumed in the building, how much it costs and what are the effective factors on these results by simulating the buildings. In order to simulate a building, after management of all options related to drawn building, Simulation was clicked in Screen tabs on the building level. As can be seen in Figure 39, simulation period was identified from 1 April to 30 September and in order to evaluate whether there is overheating or not in the base building, CIBSE TM52 was turned on in the output tab. After simulation, all results were evaluated by changing the data from display options as comfort, internal gains and fuel breakdown and solar gain, operative temperature, relative humidity, daylight factor, lighting load and cooling load were considered.

4. Results and Discussion

Analysing methodology is a very significant process to get reliable results in the scientific research. Even if all methods are applied properly if analyzing methods are not identified carefully and if there are some mistakes while evaluating the results, it means that the study will not give real results.

4.1. Overheating analysis methods and results

This study aims to reduce overheating effects while maintaining the lighting comfort, therefore the base case building was analyzed without any changing in order to show whether there is overheating or not. In order to calculate it, first of all, the cooling mode was turned off as can be seen Figure 40.

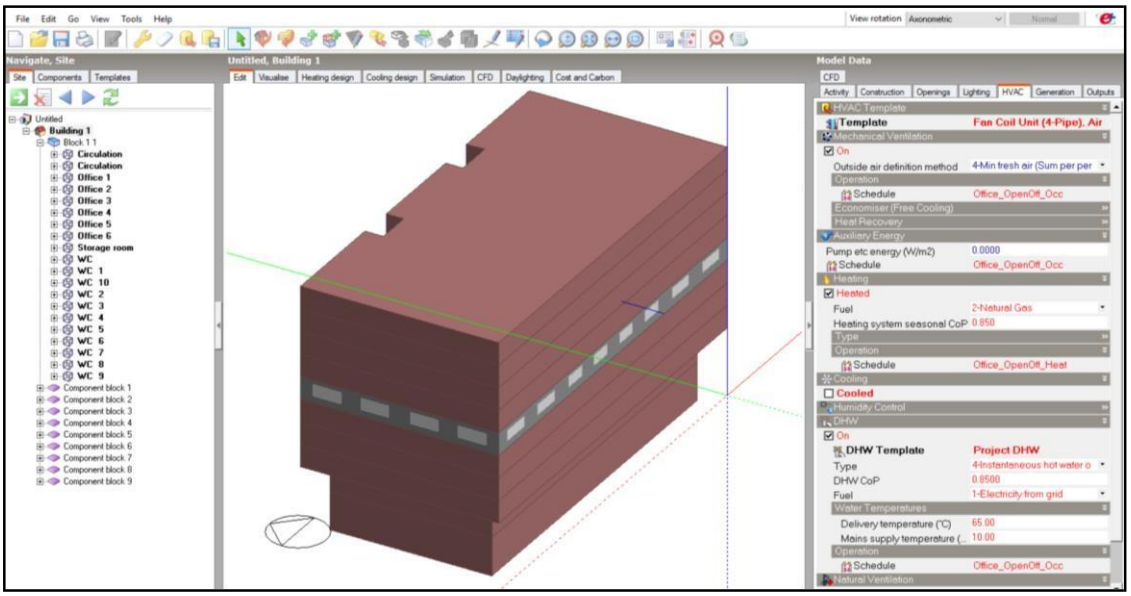


Figure 39: Turning off the cooling mode

After simulation process, View energy plus results button in the toolbar was clicked and selected eplusout.eso file to export data to Energy plus (See in Figure 41). In Designbuilder Results Viewer, as can be seen in Figure 42 and 43, Criterion 1 is calculated on annual basis and Criterion 2 is calculated on daily basis. Therefore, the related criteria were selected according to their names and they were examined in the software but if it is necessary they can be exported to an Excel sheet as well.

As can be seen from Figure 44 and 45, the model fails in both Criterion 1 and Criterion 2. In terms of Criterion 1, the occupied hours showing more than 1 K over the adaptive comfort should not be more than 3% during the non-heating season but in this case, it can be seen the values over 50% (See in Figure 44). Also, for Criterion 2, defined thresholds in any day cannot be exceeded more than 6 degree-hours a day but Figure 45 shows that it fails from criterion 2 as well. Therefore, in terms of CIBSE three-criterion system, because of failing in any two of three criteria, the building is regarded as overheating.

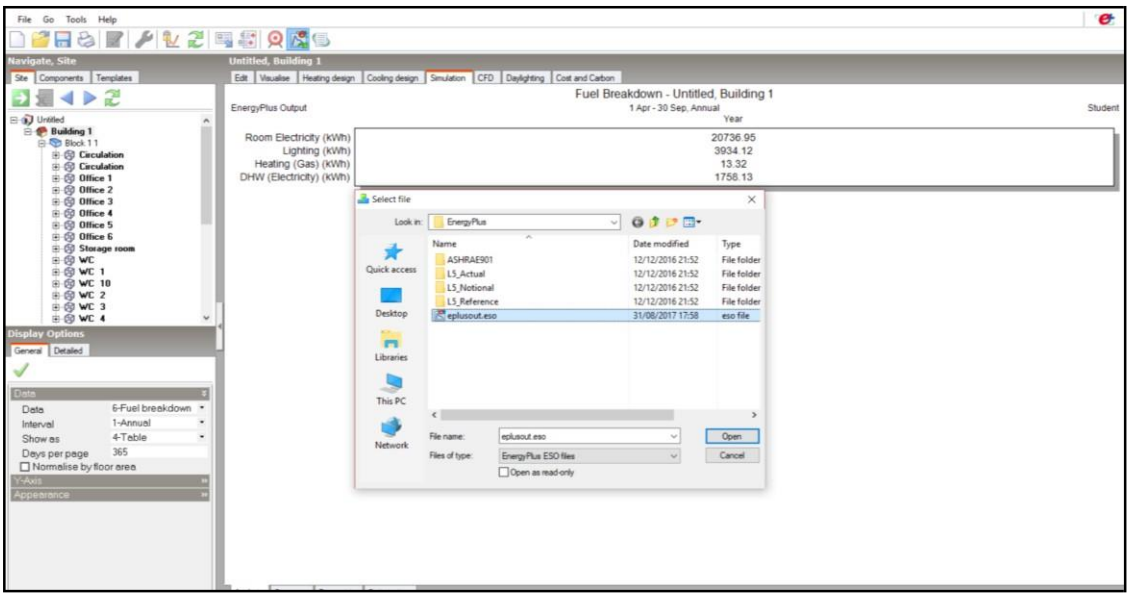


Figure 40: Export the data to Energy plus

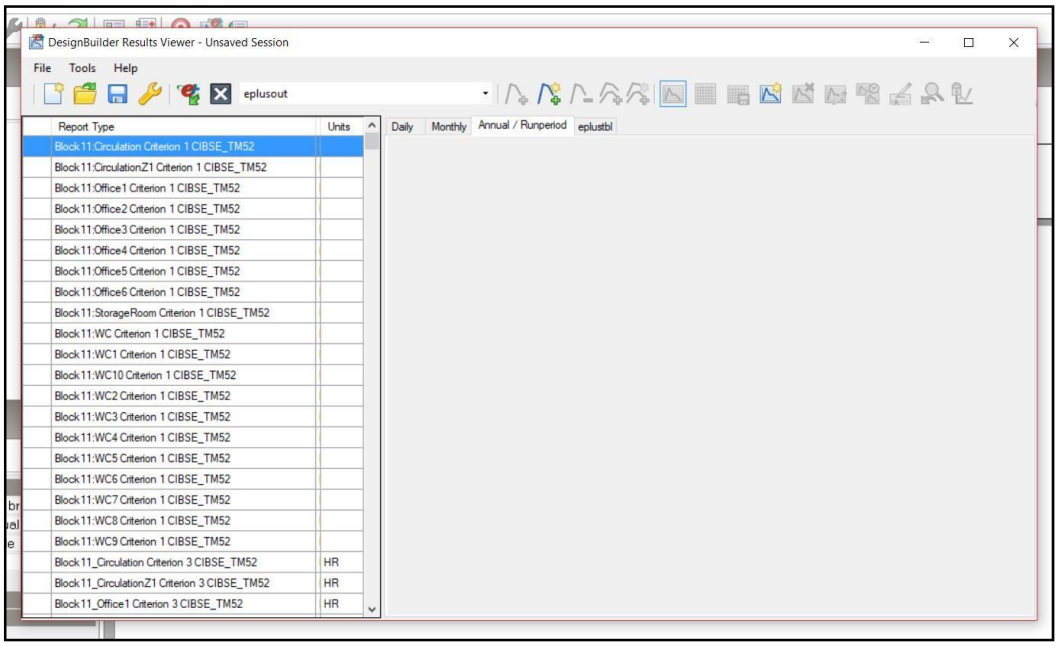


Figure 41: Criterion 1 on annual basis

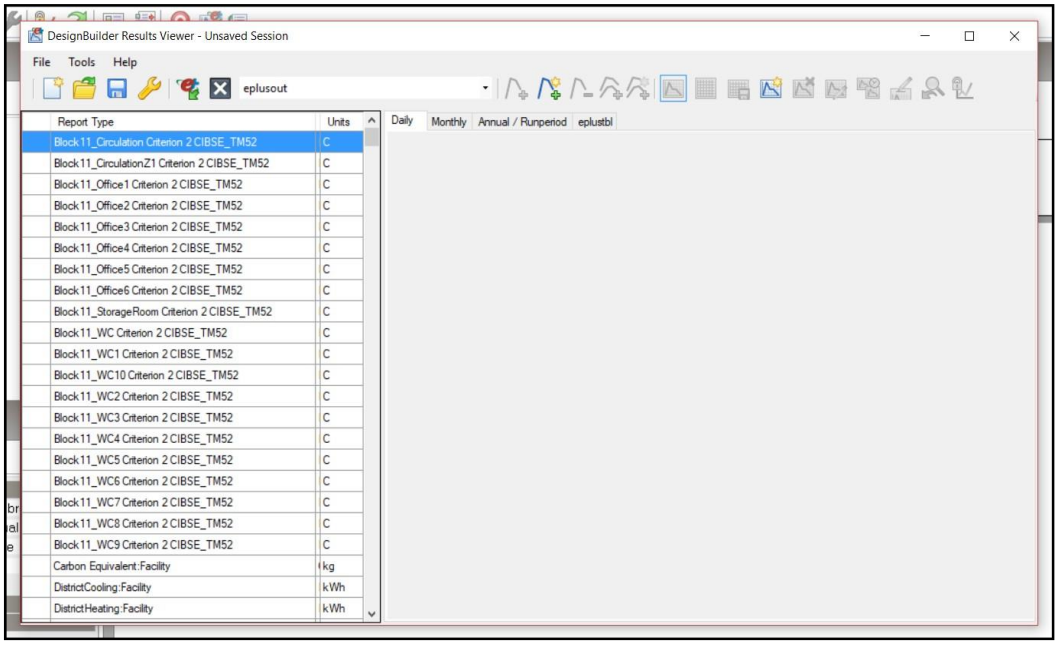


Figure 42: Criterion 2 on daily basis

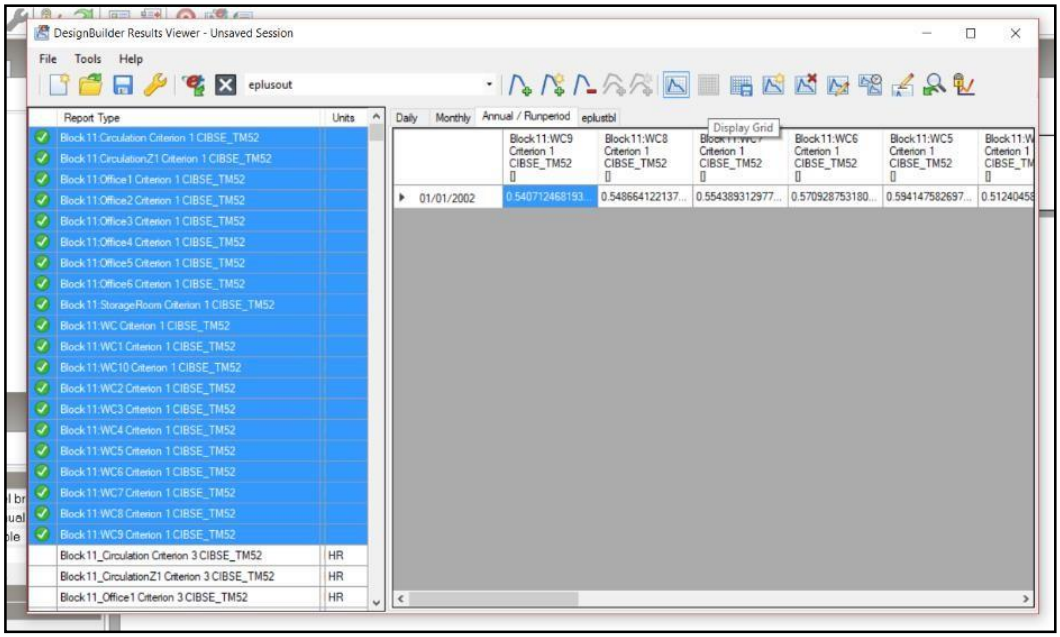


Figure 43: Getting results in Result viewer for Criterion 1

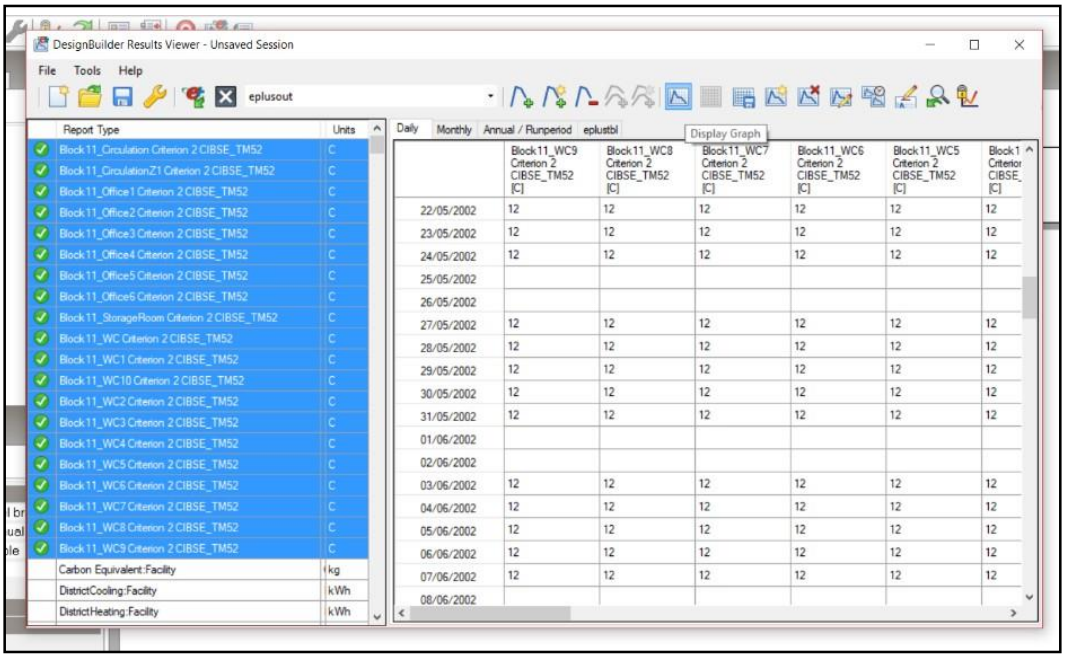


Figure 44: Getting results in Result viewer for Criterion 2

4.2. Analysis of the results obtained from simulations

As can be seen in the results obtained from simulations, many graphs were created in order to analyze them and try to understand the effect of each factor on each direction. For this purpose, each variable was simulated on each direction while other variables were being kept constant and solar gain, operative temperature, relative humidity, daylight factor, lighting load and cooling load results were written to Excel sheets (See Appendix 1). At the end of this process, all data were converted into some graphs to present them properly. While creating the graphs, for the purpose of showing the best relationship, regression lines were drawn by using the least squares criterion. As can be seen in Figure 45, this method aims to draw lines or curves by keeping the distance minimum between the drawn line and real values. Therefore, thanks to this method, it is possible to draw more accurate graphs.

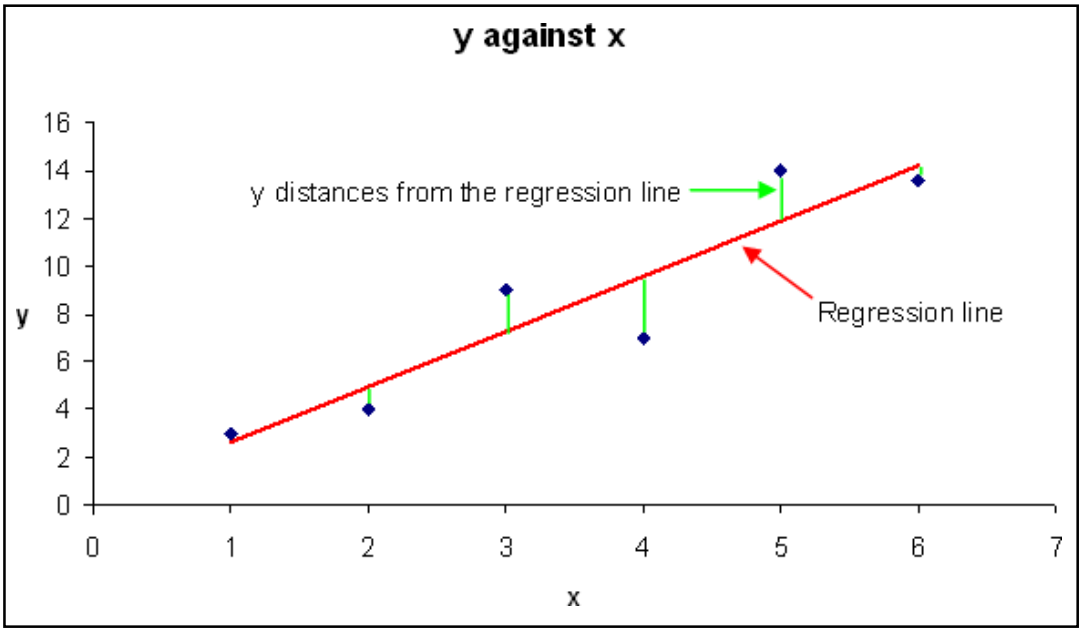


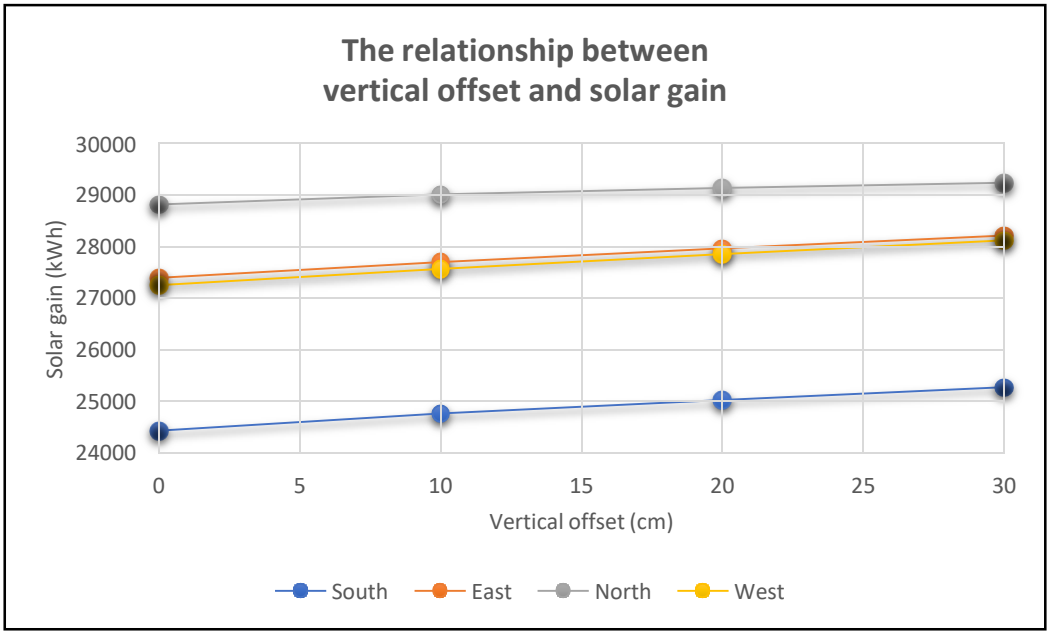
Figure 45: The least squares criterion (Inferentialthinking,2016)

4.2.1. Overhang variable results

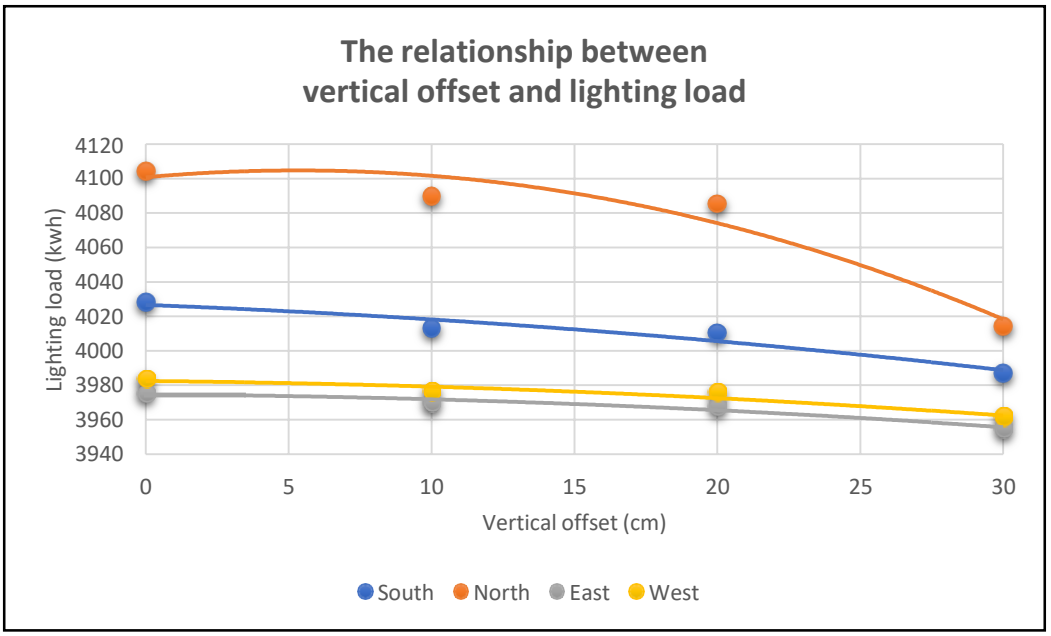
4.2.1.1. Vertical offset

Overhang shading devices were evaluated on the basis of three main factors as vertical offset, projection and horizontal overlap (See their graphs in the following sections).

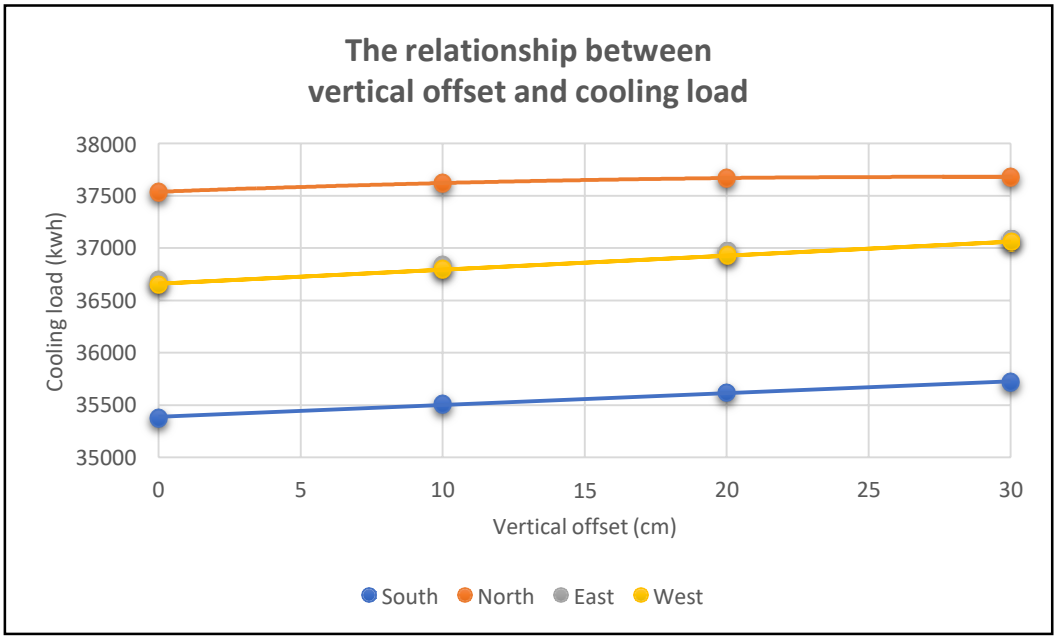
First of all, as can be seen in Graph 1, vertical offset factor of the overhang is directly proportionate to solar gain. On the based on orientation, as long as vertical offset dimensions increase, the most affected orientation from solar gain is South with 3% followed by West. Also, with the increase of vertical offset factor, lighting loads especially the load on North direction shows substantially decline while cooling load remains to slightly increase.



Graph 1: The effect of vertical offset variable on solar gain of the building



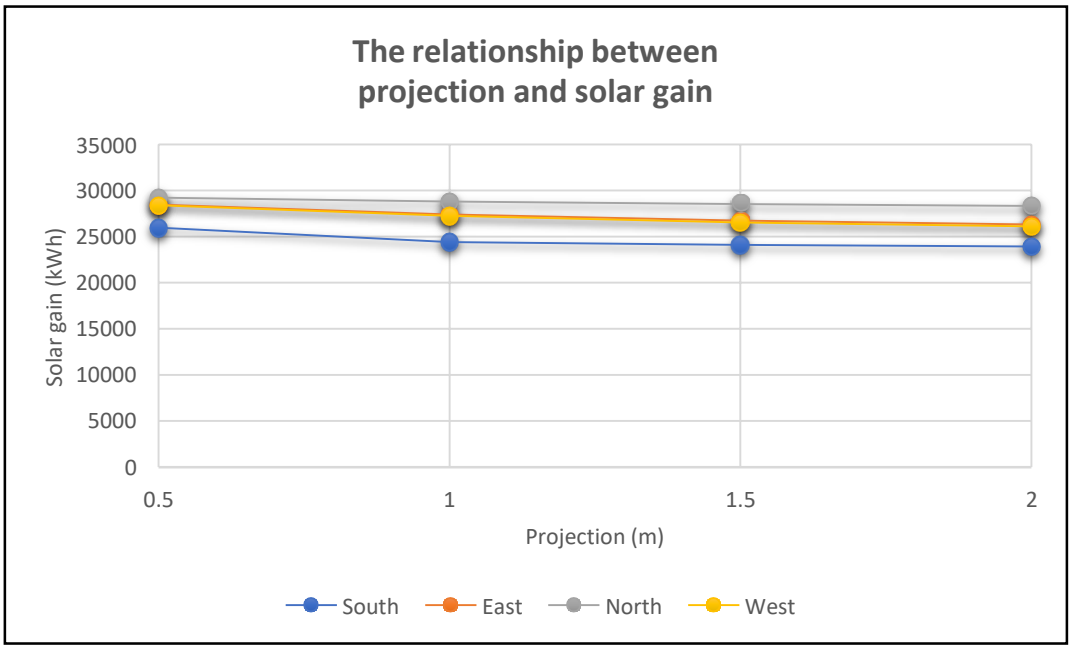
Graph 2: The effect of vertical offset variable on lighting consumption



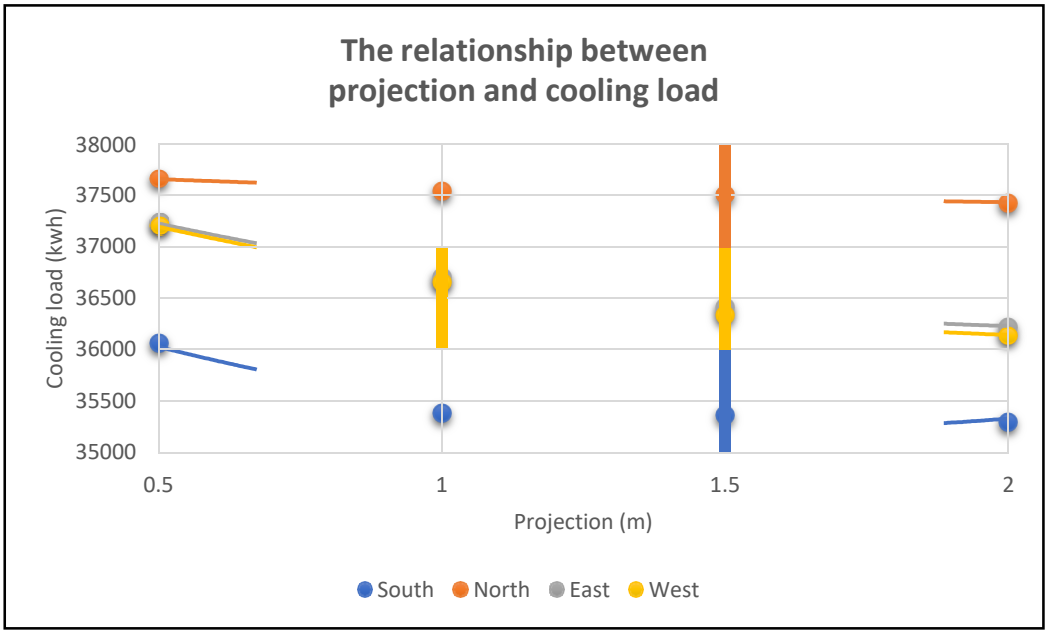
Graph 3: The effect of vertical offset variable on cooling consumption

4.2.1.2. Projection

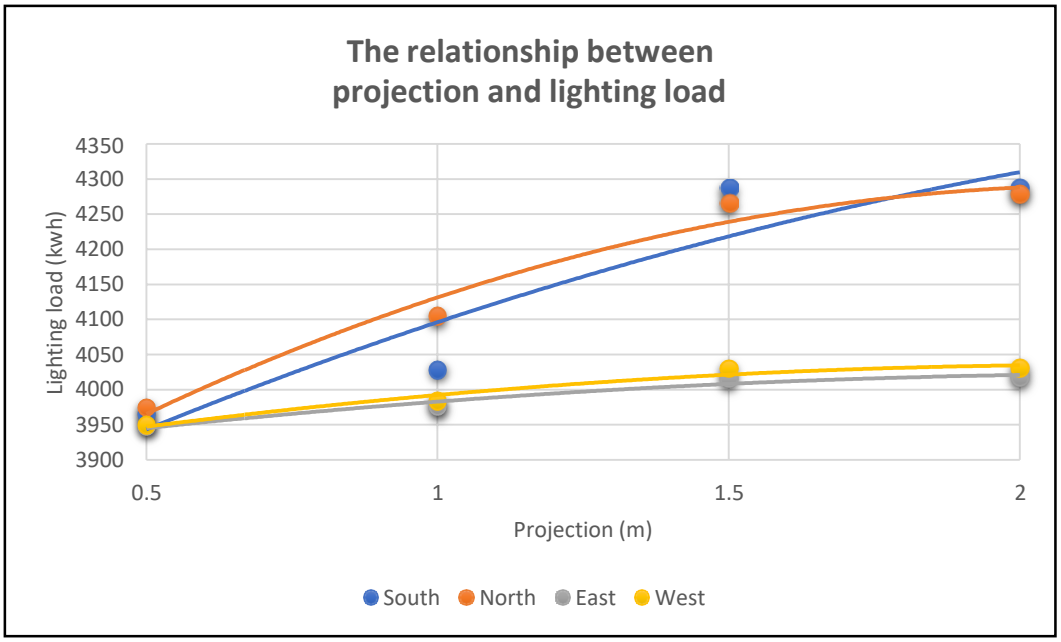
On the other hand, as can be seen in following graphs, when the solar gain with the increase of overhang projection was analyzed, it can be seen that all orientations except for North show substantial reduction in solar gain as long as the projection length of the overhang increases. Opposite of this situation, one of the most affected orientation by the solar gain in terms of lighting load is North as well while its cooling load shows slightly difference on the percentage based. Additionally, although solar gain reduction percentages with the increase of overhang projection in South and West are approximately the same, their lighting loads have a considerable difference. Also, East and West direction behaviors look like each other against to the change of projection.



Graph 4: The effect of projection variable on solar gain of the building



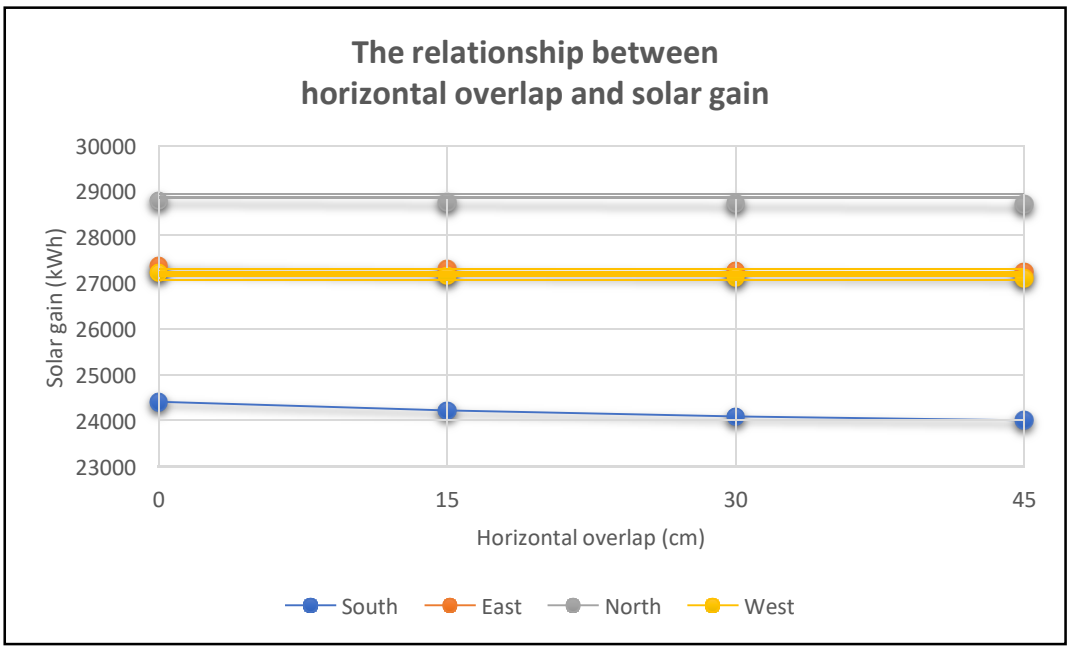
Graph 5: The effect of projection variable on cooling consumption



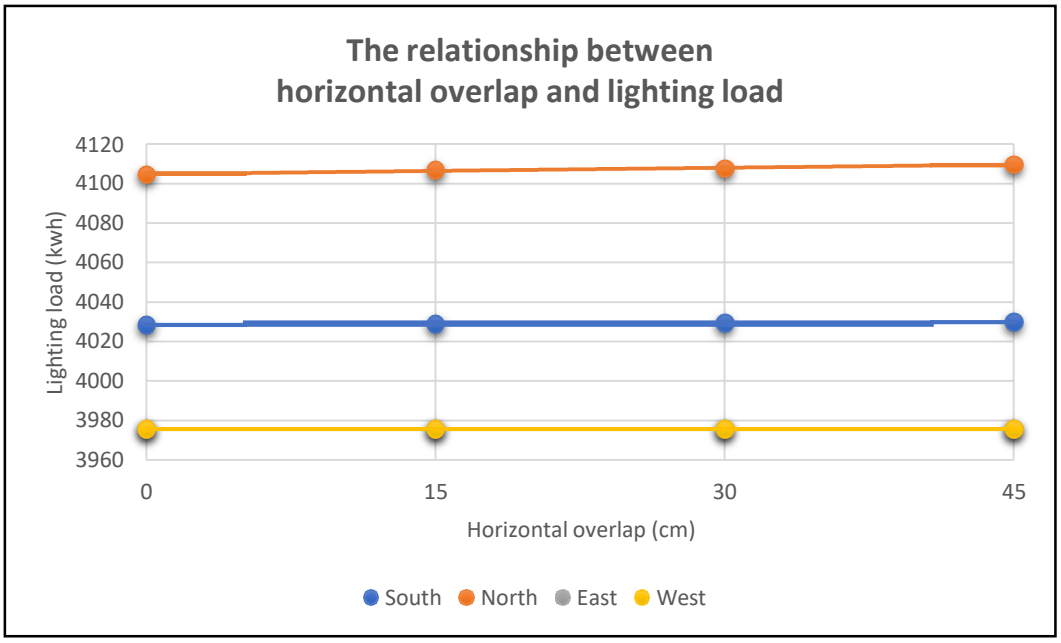
Graph 6: The effect of projection variable on lighting consumption

4.2.1.3. Horizontal overlap

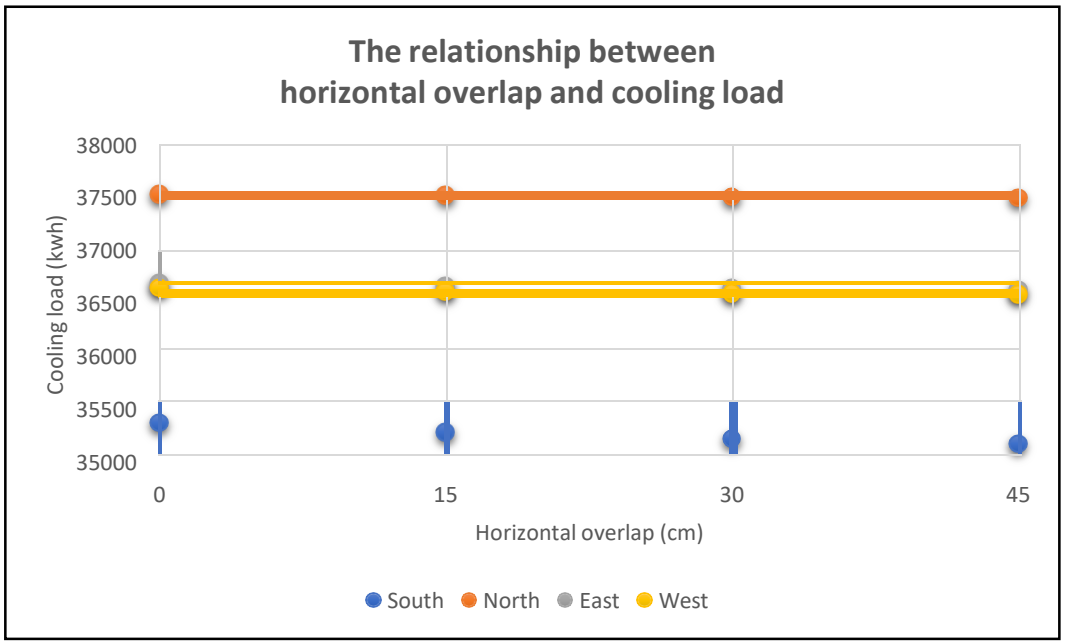
When the horizontal overlap factor of the overhang is compared with vertical offset and projection, it can be seen from the graphs, the horizontal overlap is not an effective factor to show a huge alteration in solar gain and indirectly cooling and lighting loads as well. Also, West and East behaviors against to solar gain and their energy contributions are similar. Although the most affected orientation by horizontal overlap change is south in terms of solar gain, the biggest percentage of increase in lighting load is shown by North orientation with the alteration of horizontal overlap factor.



Graph 7: The effect of horizontal overlap on solar gain of the building



Graph 8: The effect of horizontal overlap on lighting consumption



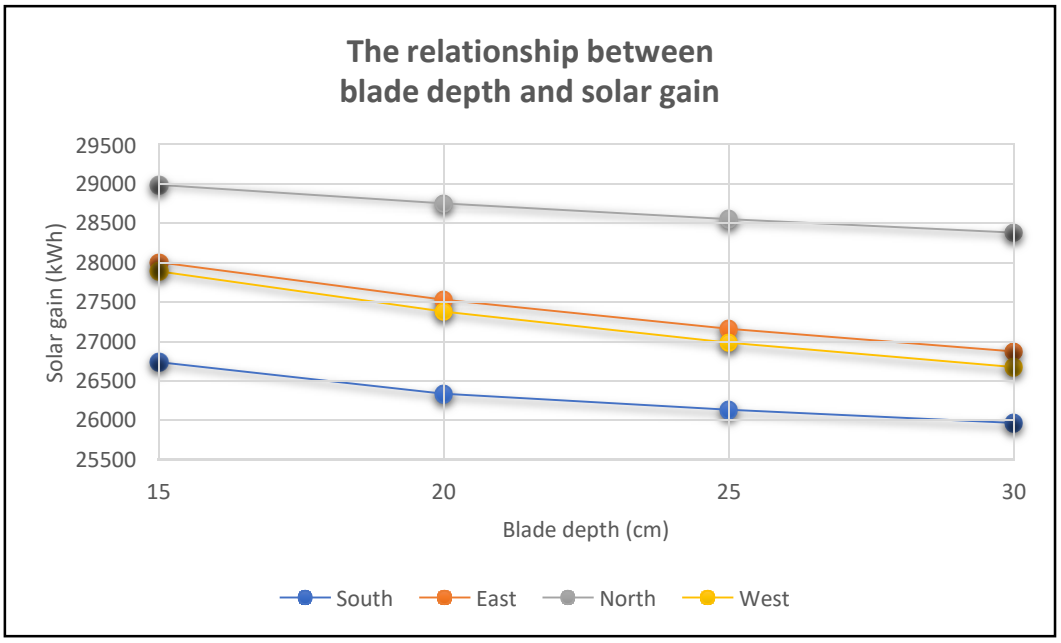
Graph 9: The effect of horizontal overlap on cooling consumption

4.2.2. Louvre variable results

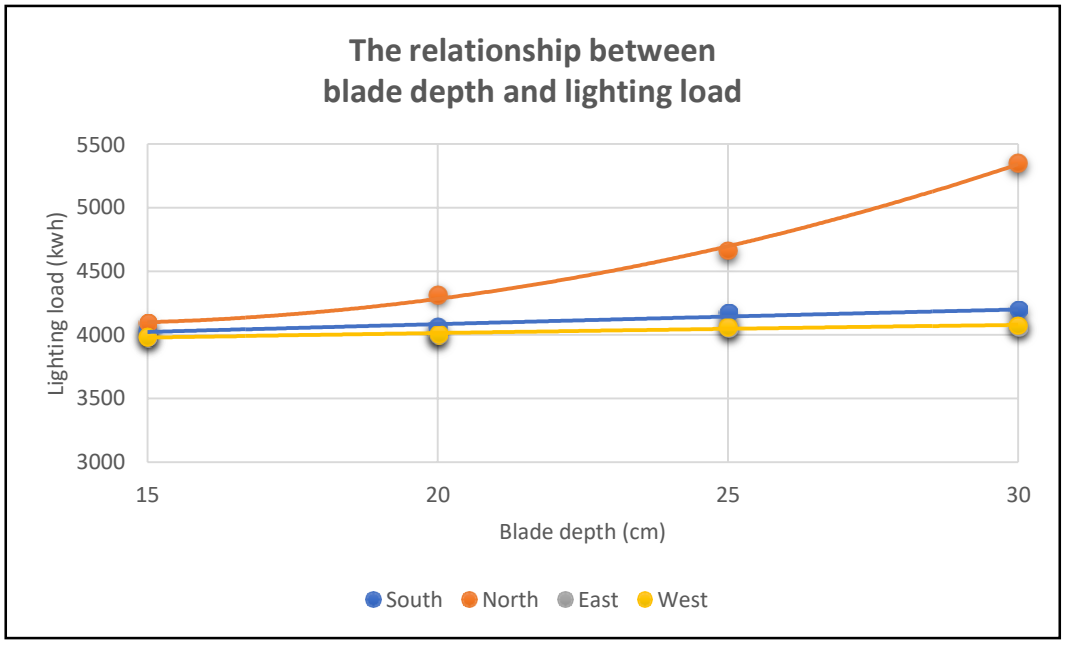
4.2.2.1. Blade depth

In this study, louvre shading devices were analyzed on the basis of four main factors as blade depth, vertical spacing, angle and distance from the window (See their graphs in the following sections).

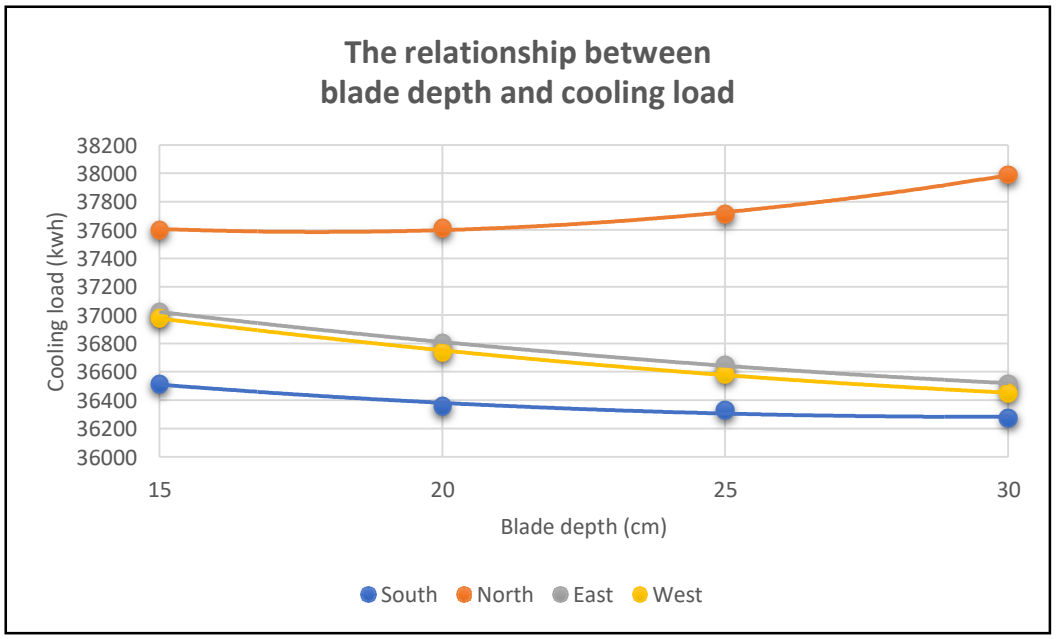
First of all, as can be seen in blade depth graphs, although the least affected orientation by the blade depth increase in terms of solar gain is North, it shows a huge alteration in the lighting load despite reasonable cooling load. On the other hand, the increase of cooling load for north direction is an opposite behavior to other directions as long as blade depth shows a rise.



Graph 10: The effect of blade depth on solar gain of the building



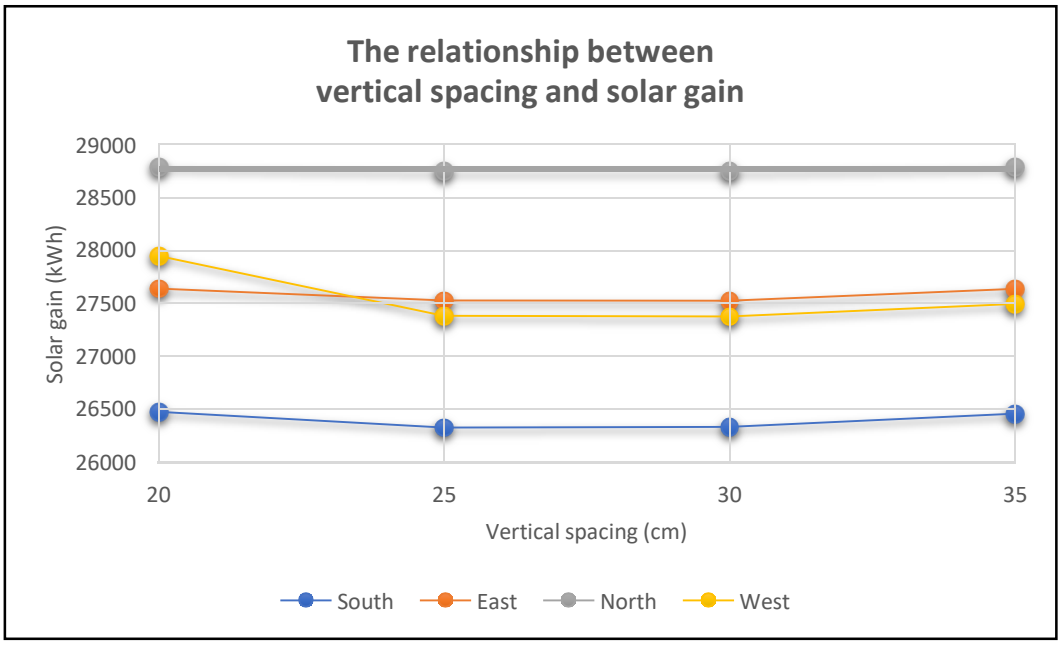
Graph 11: The effect of blade depth on lighting consumption



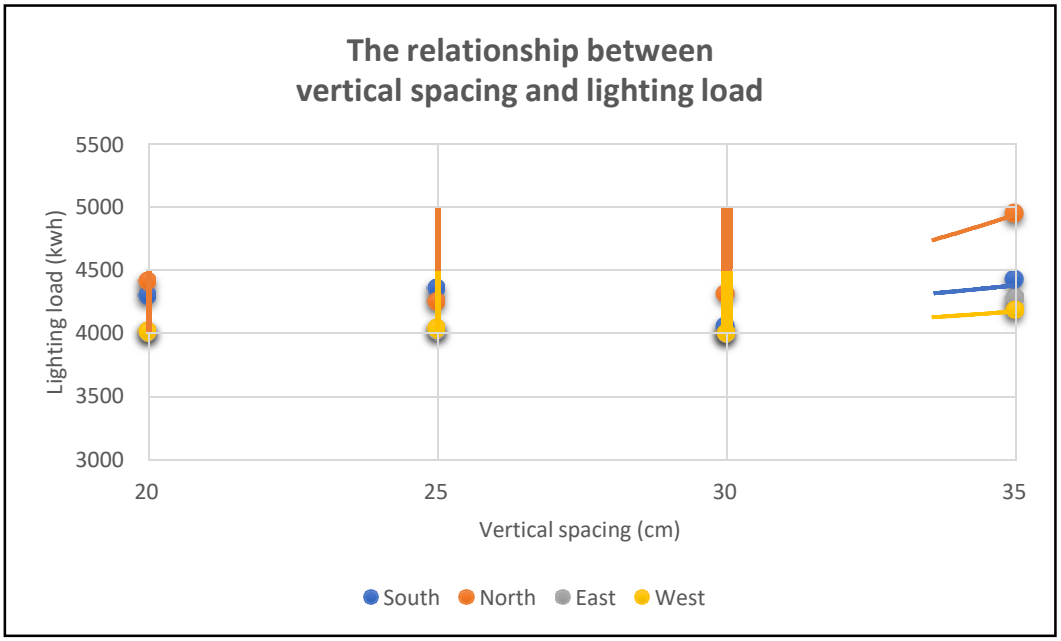
Graph 12: The effect of blade depth on cooling consumption

4.2.2.2. Vertical spacing

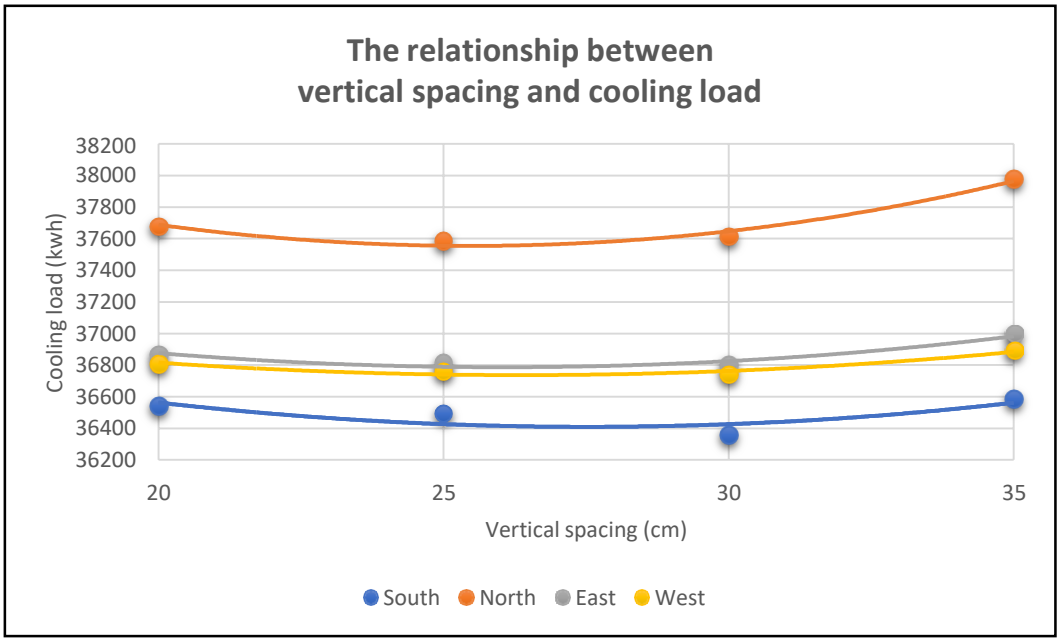
As can be seen from the graphs, similar to blade depth, although the north orientation has the minimum solar gain change with the increase of vertical spacing, its increase in lighting load attracts notice by followed east. Also, although west orientation is more sensitive to solar gain with the increase of vertical spacing rather than east, as long as vertical spacing dimension increases from 20 to 35 centimeter, the cooling load of east orientation increases more than west.



Graph 13: The effect of vertical spacing on solar gain of the building



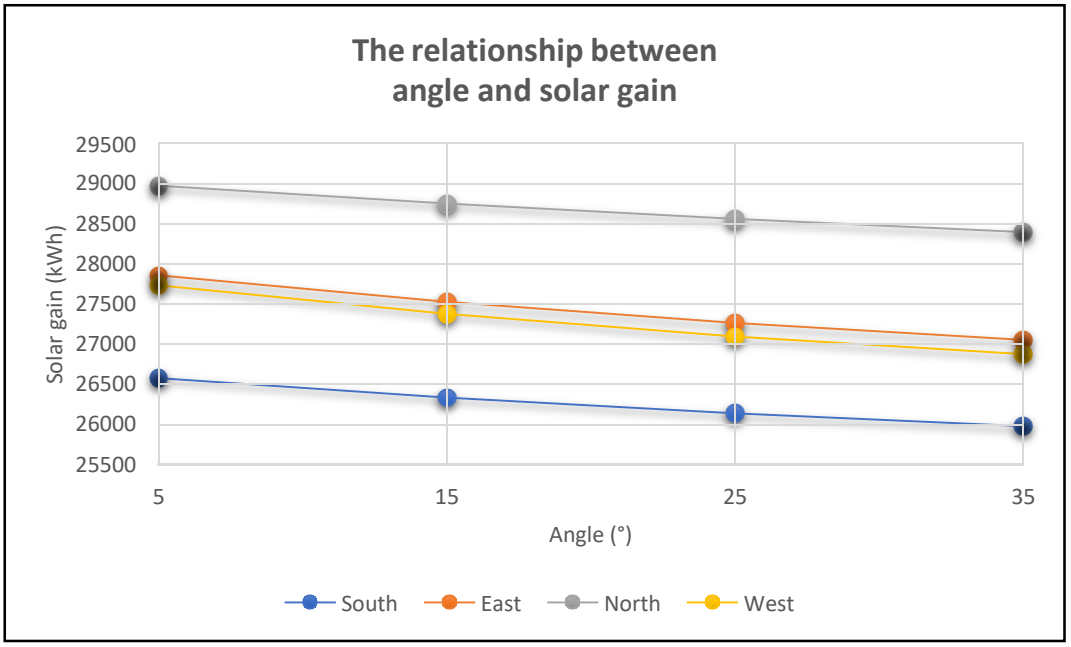
Graph 14: The effect of vertical spacing on lighting consumption



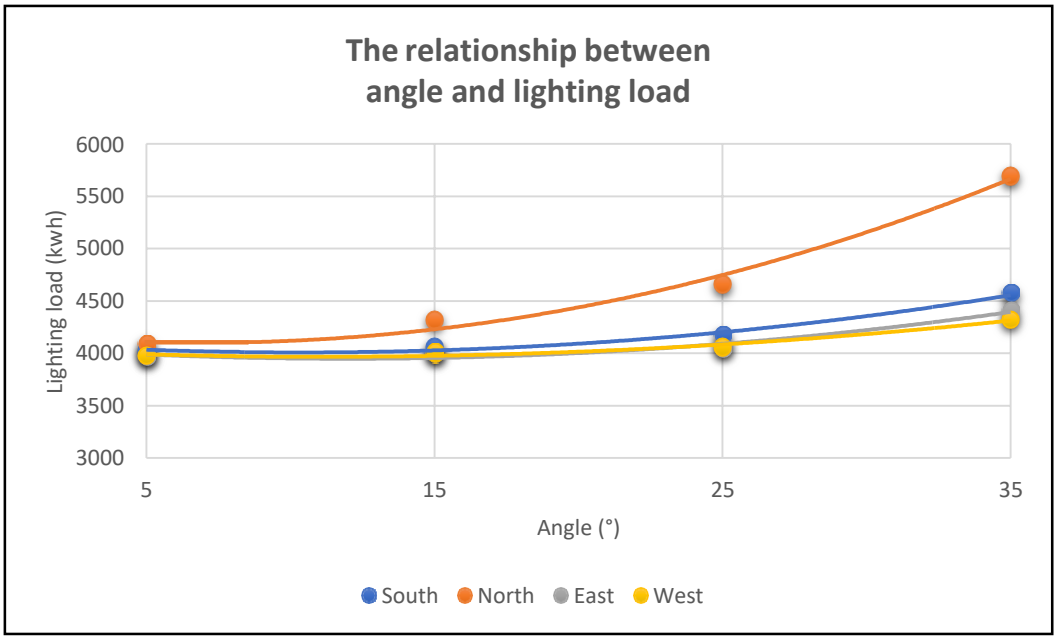
Graph 15: The effect of vertical spacing on cooling consumption

4.2.2.3. Angle

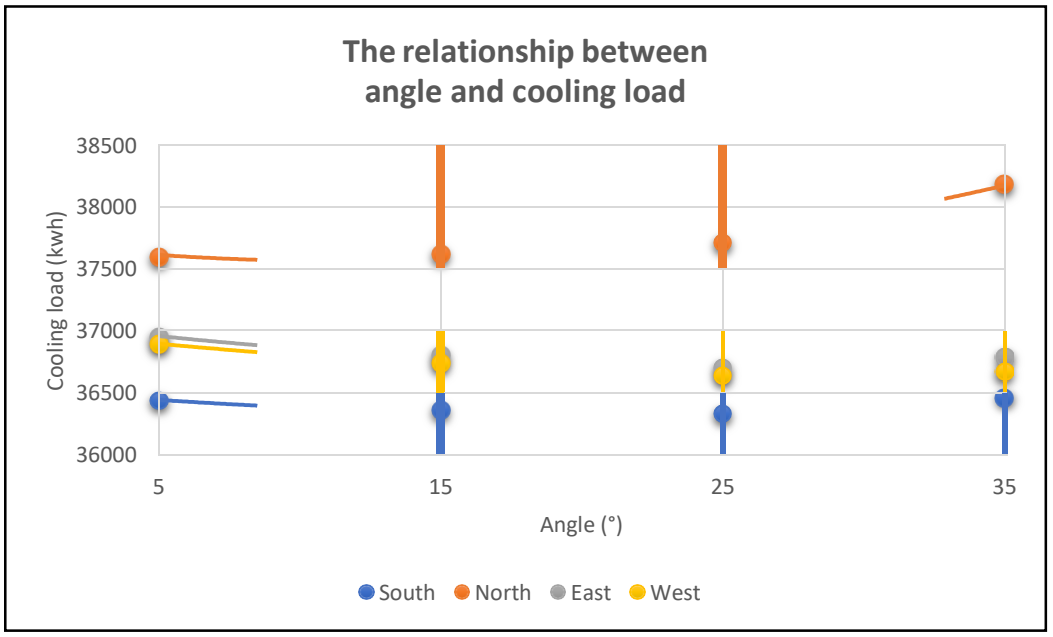
As can be seen in the following graphs, the most solar gain on the base of orientation belongs to north orientation. Also, similar to other factors, despite the least solar gain change thanks to louvre angle, north shows the biggest percentage of cooling load increase surprisingly. Additionally, although south direction has less solar gain than others, its lighting load shows similarity with others' loads against to outstanding cooling load. Besides, the difference of louvre angle from 5° to 35° does not show worth considering a change in lighting load against to 11% of the increase in cooling load on south direction.



Graph 16: The effect of angle variable on solar gain of the building



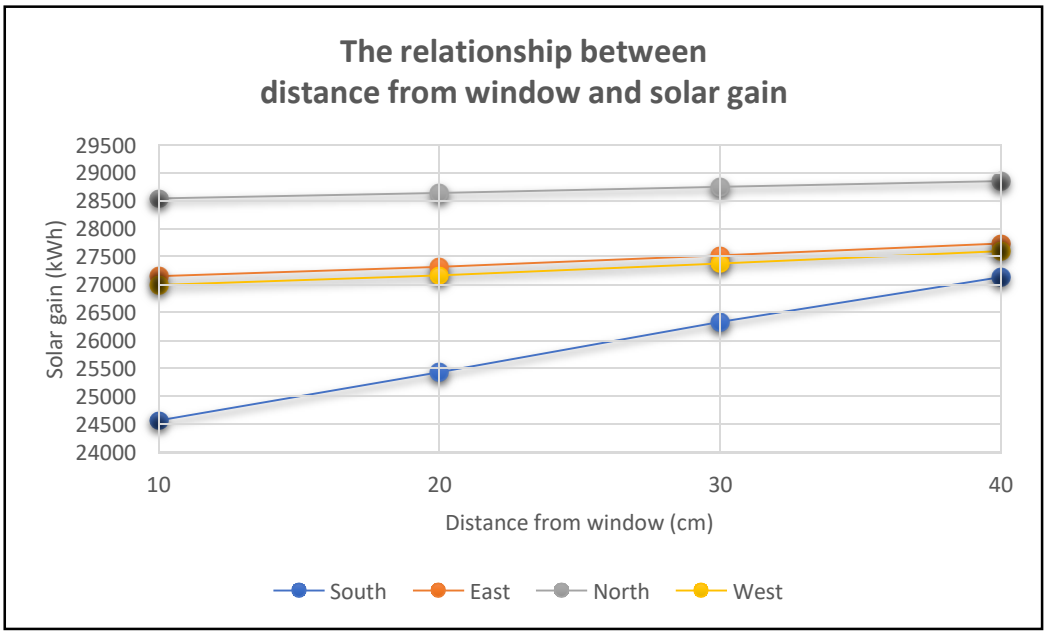
Graph 17: The effect of the angle on lighting consumption



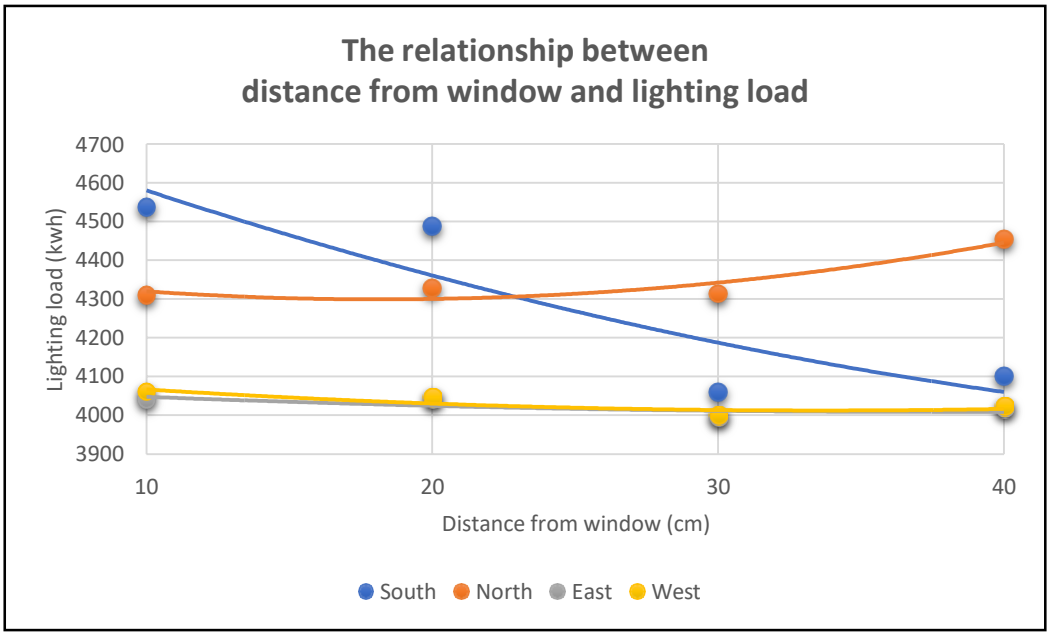
Graph 18: The effect of the angle on cooling consumption

4.2.2.4. Distance from the window

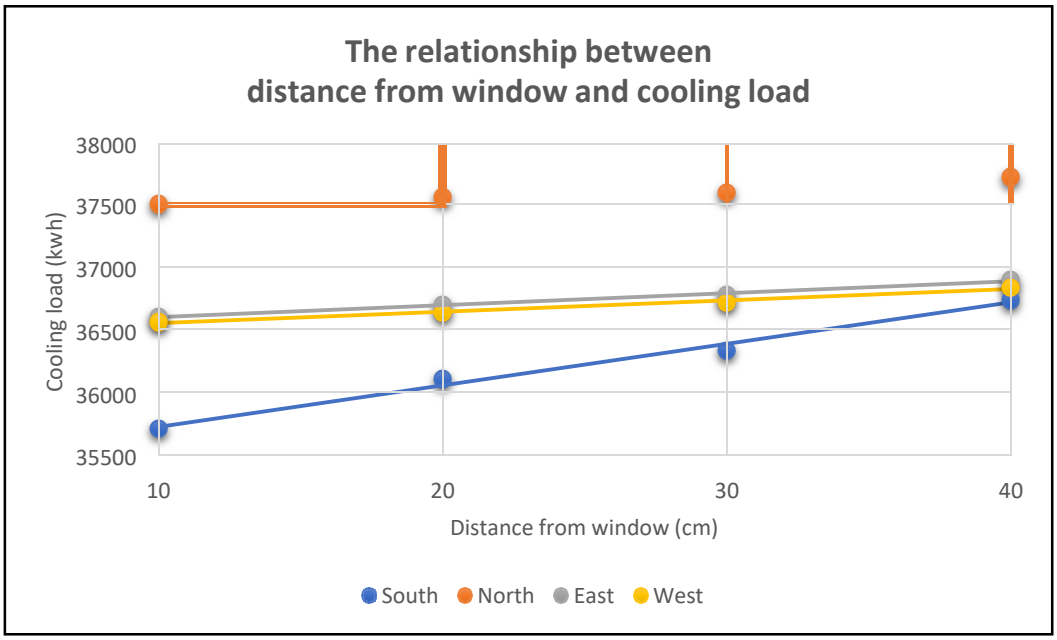
The most attention-grabbing behavior of louvre distance from window change undoubtfully belongs to south orientation. As long as the distance from the window increases, although other orientations change slightly, south direction shows a huge alteration with 9.4% increase in solar gain and 10.6% decrease in lighting load. Despite more cooling load possession on south direction than others, cooling load on south direction is not too sensitive to distance from the window like lighting load. Additionally, the most affected orientation by the change in distance from the window after south in lighting load is north and also its opposite behavior differs from others.



Graph 19: The effect of distance from window on solar gain of the building



Graph 20: The effect of the distance from window on lighting consumption



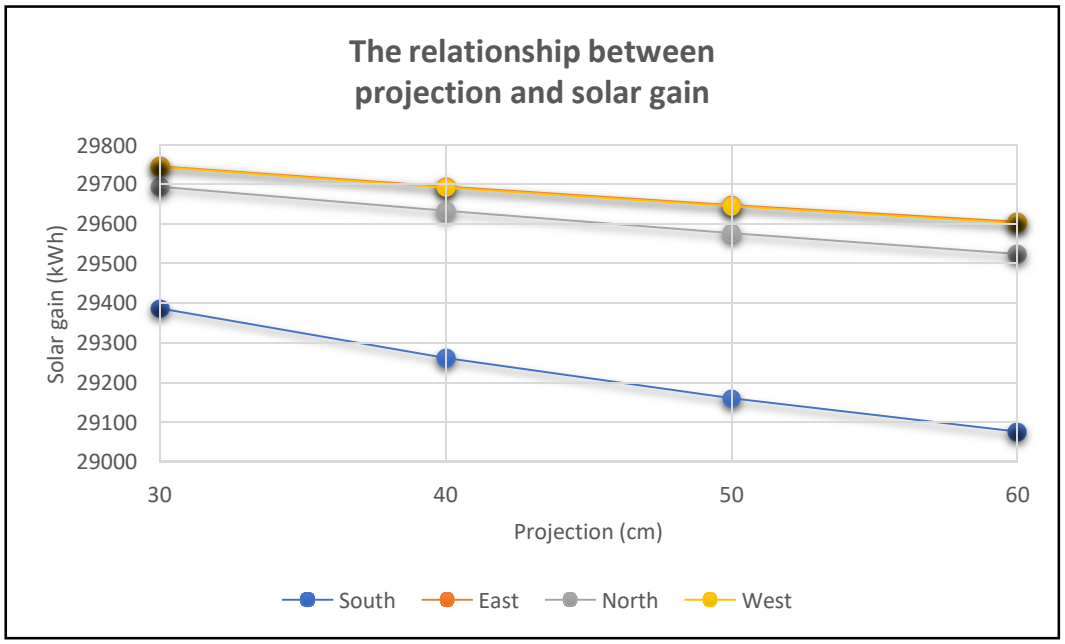
Graph 21: The effect of the distance from window on cooling consumption

4.2.3. Sidefin variable results

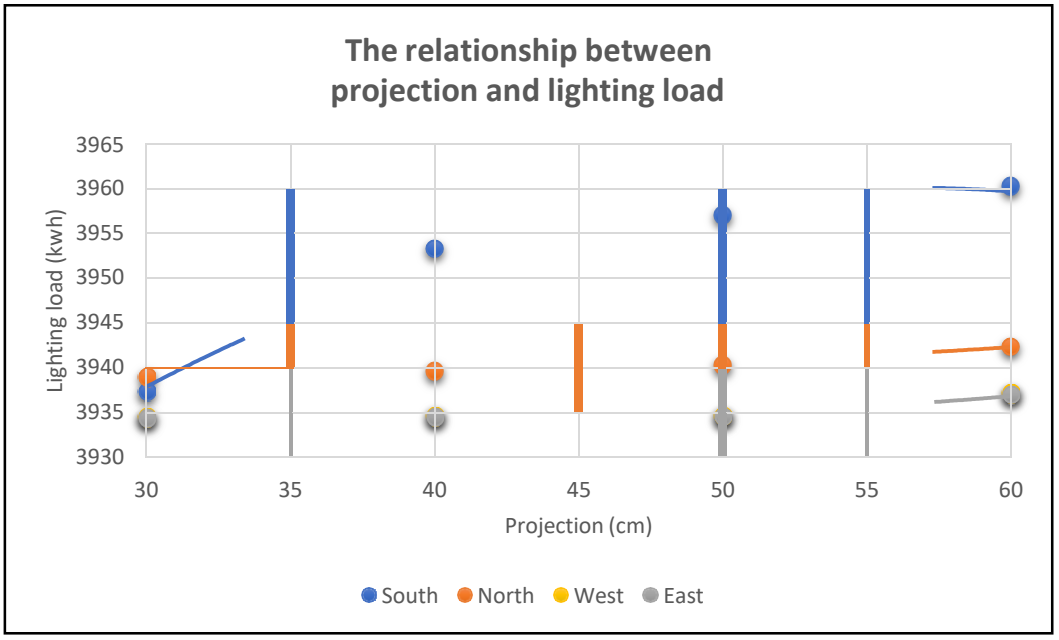
4.2.3.1. Projection

In this study, sidefin shading devices were analyzed on the basis of three main factors as projection, horizontal offset and top and bottom overlap (See their graphs in the following sections).

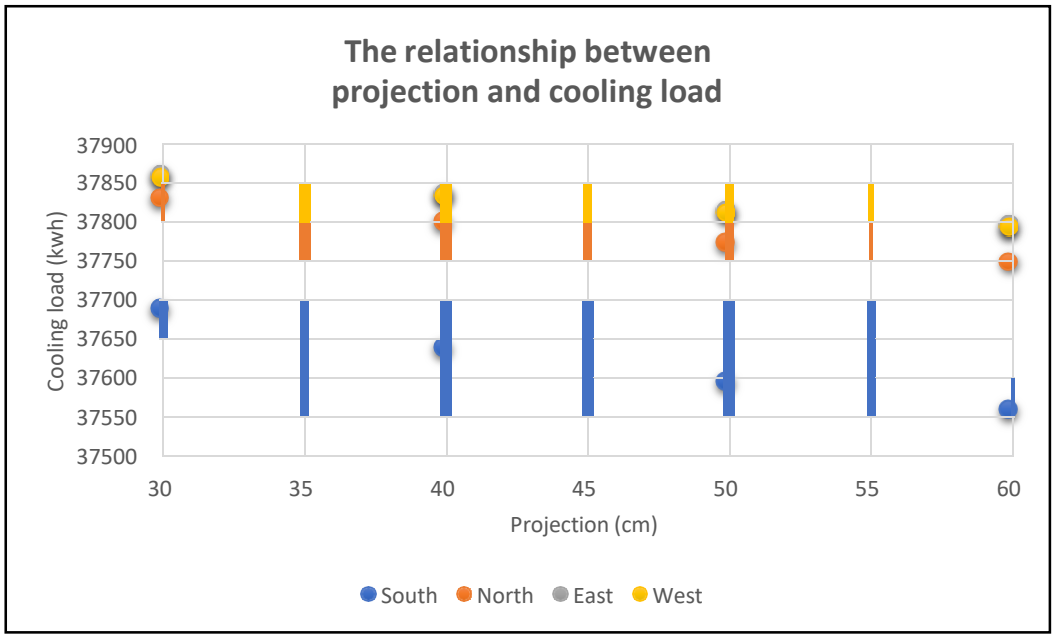
First of all, as can be seen from the following graphs, the percentage of change on the base of projection factor is too little compared to overhang and louvre results. In this case, south orientation differs from others with the sensibility of projection change. Also, its behavior against to the increase of projection stands out in lighting load.



Graph 22: The effect of projection on solar gain of the building



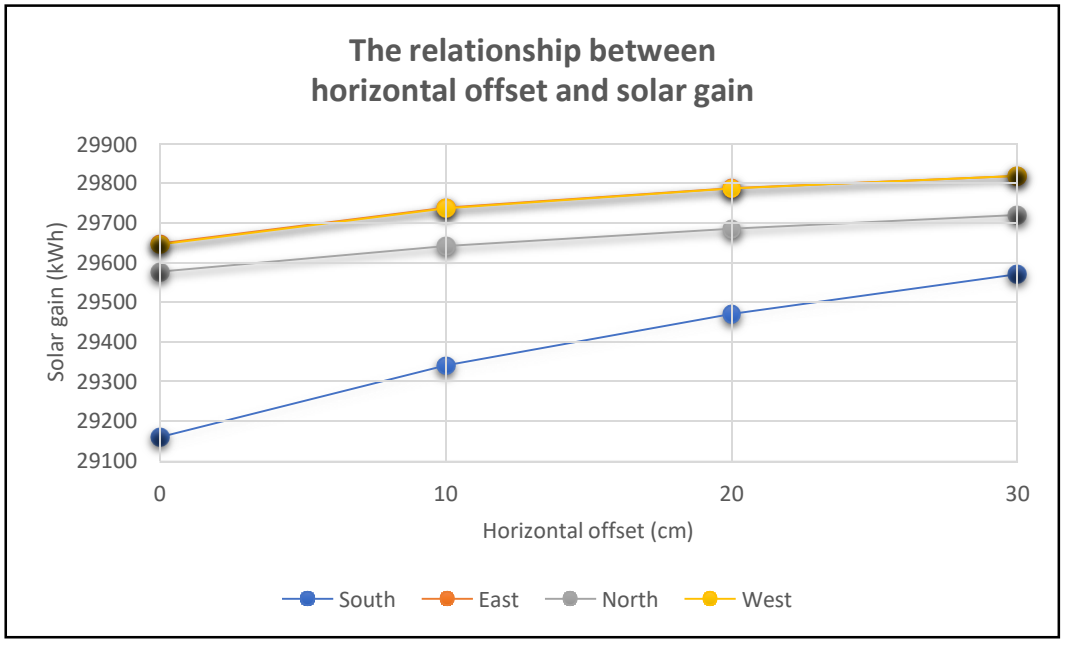
Graph 23: The effect of the projection on lighting consumption



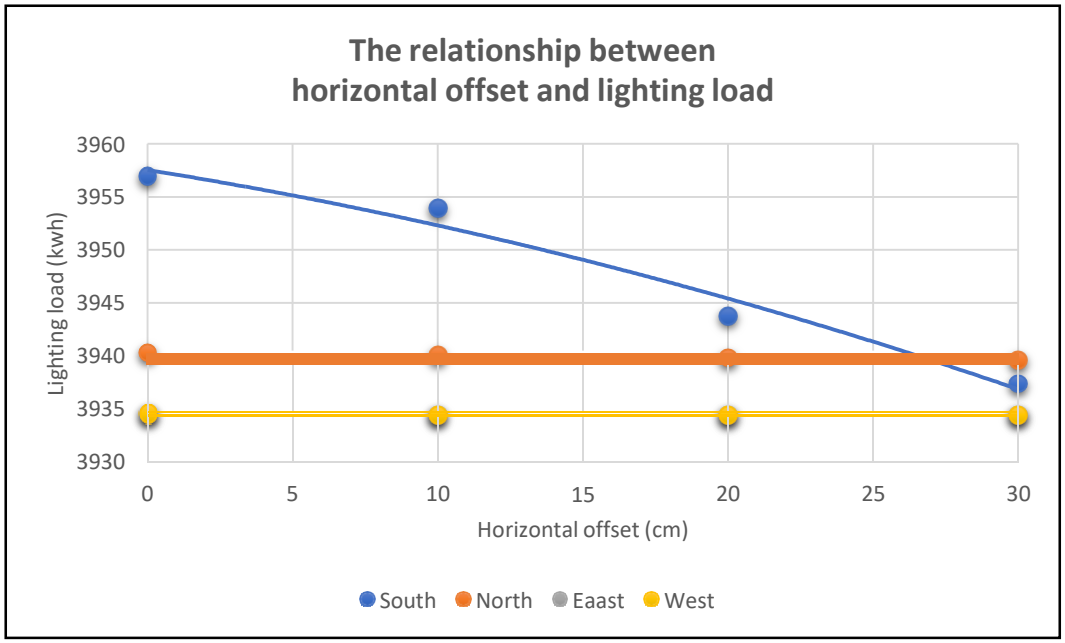
Graph 24: The effect of the projection on cooling consumption

4.2.3.2. Horizontal offset

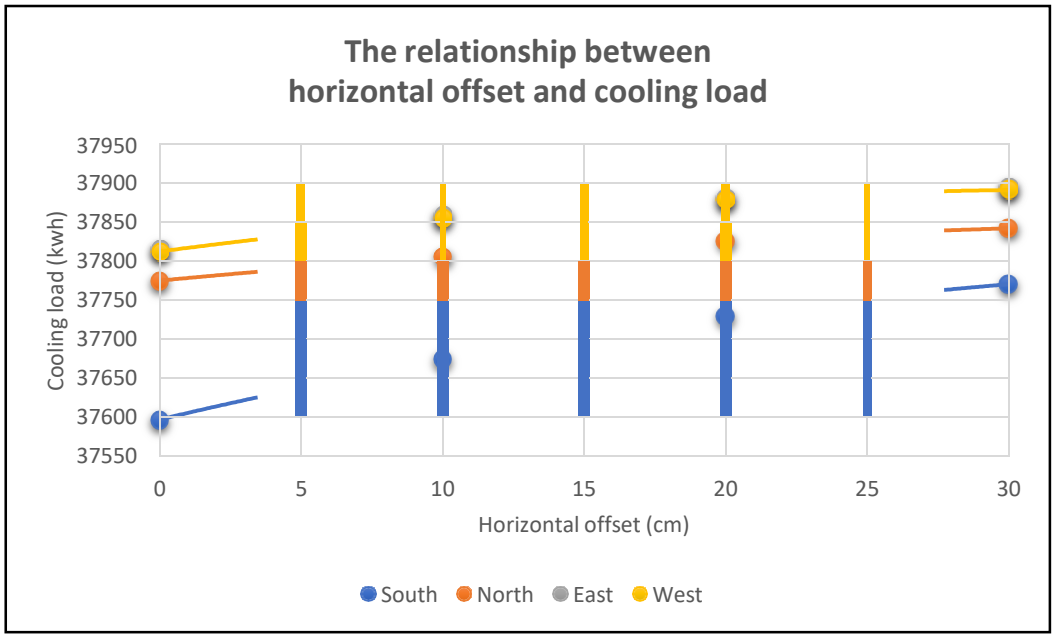
As can be seen from the following graphs, horizontal offset factor of sidefin shading devices has more impact on south direction than others. As long as horizontal offset dimension increases, it can be seen a great increase of solar gain and cooling load on south direction against to outstanding decrease in lighting load. Additionally, although approximately all overhang and louvre factors show the biggest solar gain on north direction, sidefin solar gain graphs indicate that east, west and north directions have similar potential in terms of solar gaining.



Graph 25: The effect of horizontal offset on solar gain of the building



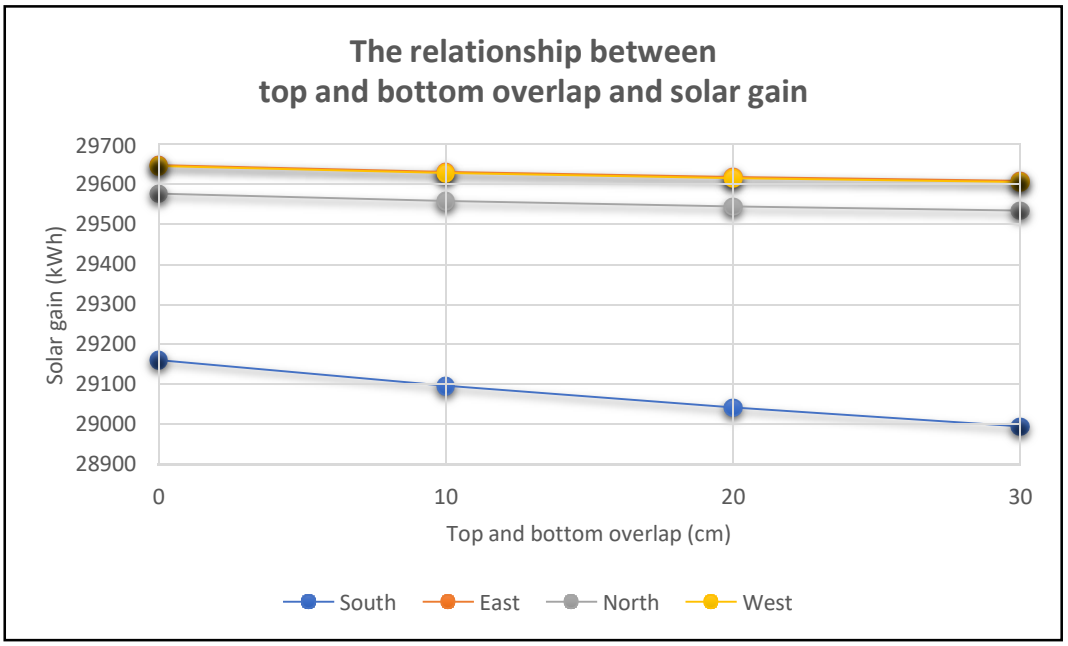
Graph 26: The effect of the horizontal offset on lighting consumption



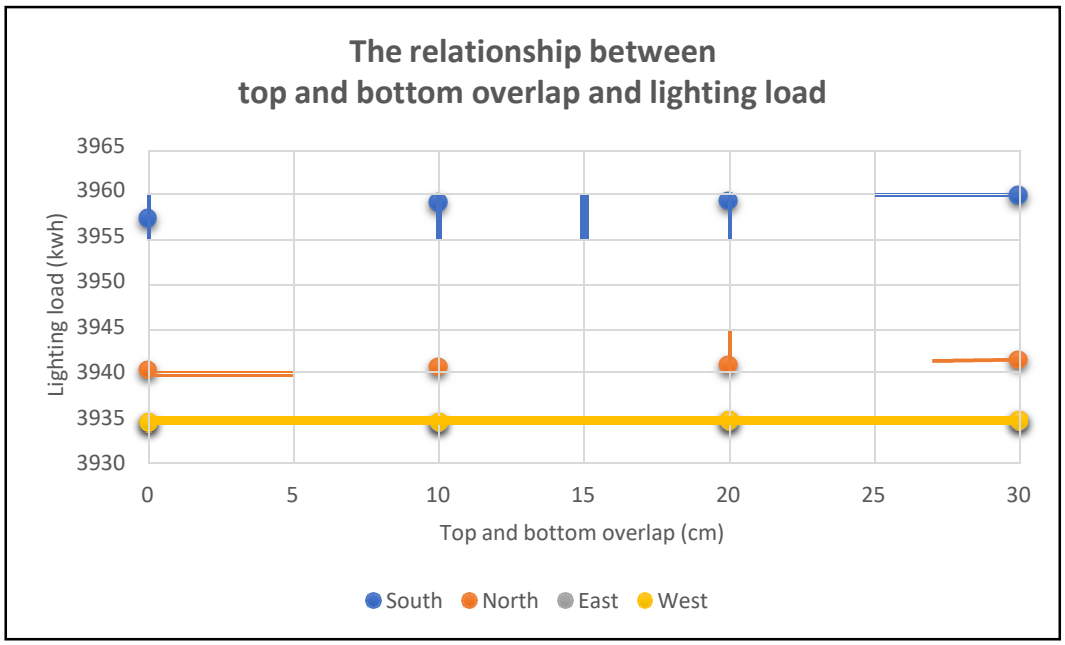
Graph 27: The effect of the horizontal offset on cooling consumption

4.2.3.3. Top and bottom overlap

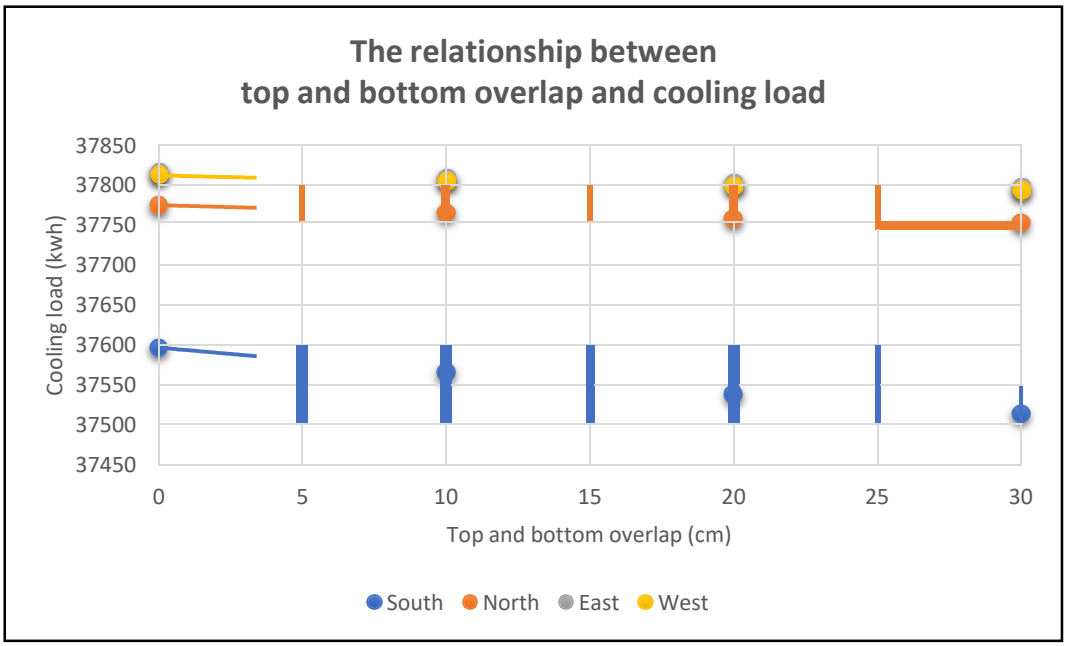
As can be seen in following graphs, top and bottom overlap factors in sidefin shading devices do not have a significant effect on solar gain, cooling and lighting loads. On the other hand, the effectivity of top and bottom overlap on south direction is biggest with 0.55% of solar gain and 0.22% of cooling load change differing from other dimensions. Additionally, although west, east and north solar gains similar to each other, west orientation differentiates with the least lighting load and the biggest cooling load with small percentage differences.



Graph 28: The effect of top and bottom overlap on solar gain of the building



Graph 29: The effect of top and bottom overlap on lighting consumption



Graph 30: The effect of top and bottom overlap on cooling consumption

4.3. Selection of the optimum results and production of final results

Normally, optimisation of cooling and lighting is conducted by some energy optimisation software but this study aims to show their relationship rather than find the optimum points. For this reason, instead of finding the best results, how the best results can be created manually and how many percentage reductions is possible in this way were tried to present in this study. In order to select the best ones, for each variable, all results for all orientations were evaluated in the Excel sheet (See Figure 23). The aim was a comparison between the base case results and the results obtained from simulations. For this purpose, these formulas were used below:

$$\boldsymbol{Lighting\ load\ improvement}\ (\%) = \frac{\text{Improved lighting load} - \text{Base case lighting load}}{\text{Base case lighting load}} \times 100$$

Equation 1: The percentage of lighting load improvement

$$\boldsymbol{Coling\ load\ improvement}\ (\%) = \frac{\text{Improved cooling load} - \text{Base case cooling load}}{\text{Base case cooling load}} \times 100$$

Equation 2: The percentage of cooling load improvement

$$\boldsymbol{Overall\ improvement\ of\ that\ factor}(\%) = \frac{Improved\ lighting\&cooling\ total - Base\ case\ lighting\&cooling\ total}{Base\ case\ lighting\&cooling\ total} \times 100$$

Equation 3: The percentage of overall improvement

As can be seen in Figure 23, for each orientation, the best results were selected for cooling and lighting load. When the best ones were analyzed, it can be seen that cooling and lighting loads behave oppositely each other. When the improvement of cooling load is maximum, the lighting load improvement percentages show the worst results. In this case, in order to optimise them, adding cooling load improvement percentage and lighting load improvement percentage do not equal to the total percentage because of differentness of base cooling and lighting loads. Therefore, for this purpose, overall total cooling and lighting loads were compared and thus, the optimum variable was gained for both of them. At the end of the process, the best variable properties were selected for each orientation to combine them in the further process.

Orientation	Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)	Lighting imp(%)	Cooling imp(%)	Total imp(%)
SOUTH	3965.7	36058.54	40024.24	-0.80	4.93	4.60
	4028.35	35379.69	39408.04	-2.40	6.72	6.23
	4285.8	35358.84	39644.64	-8.94	6.78	5.60
	4287.07	35290.5	39577.57	-8.97	6.96	5.78
NORTH	3974.11	37660.85	41634.96	-1.02	0.71	0.55
	4104.61	37539.04	41643.65	-4.33	1.03	0.53
	4265.86	37506.93	41772.79	-8.43	1.12	0.22
	4279.01	37420.93	41699.94	-8.77	1.34	0.39
EAST	3947.42	37228.25	41175.67	-0.34	1.85	1.67
	3975.53	36699.35	40674.88	-1.05	3.24	2.92
	4015.68	36411.77	40427.45	-2.07	4.00	3.55
	4018.29	36219.5	40237.79	-2.14	4.51	4.04
WEST	3950.27	37195.08	41145.35	-0.41	1.94	1.75
	3983.49	36653.81	40637.3	-1.25	3.36	3.02
	4029.96	36337.08	40367.04	-2.44	4.20	3.71
	4031.56	36135.02	40166.58	-2.48	4.73	4.23

BASE CASE RESULTS		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3934.12	37929.91	41864.03

OVERALL THE BEST RESULTS		
Orientation	Total imp(%)	Projection Values(m)
South	6.23	1
North	0.55	0.5
East	4.04	2
West	4.23	2

Table 2: The best results selection process for overhang projection variable

After selection of the best results of total improvement for each direction, according to direction, the best factor values were identified. For instance, in Table 2, the best performance was showed by 1-meter-overhang on the South direction while east and west directions show 2-meter-overhang. Also, it can be seen their impact on the total improvement on the percentage based as well (See Appendix 2 to see all factors' results) At the end of the process, the best factors for each factor and each orientation were selected to combine them.

As can be seen in Table 4, subsequent to the identification of the best results for each factor, all results gathered under the related shading type on an excel sheet (See all results in Appendix 4).

	A	B	C	D	E	F
6						
7		OVERHANG	Vertical offset	OVERALL THE BEST RESULTS		
8			from top of window	Orientation	Total imp(%)	Vertical Values(cm)
9			0,10,20,30 cm	South	6.23	0
10				East	2.92	0
11				North	0.53	0
12				West	3.02	0
13						
14			Projection	OVERALL THE BEST RESULTS		
15			0.5, 1, 1.5, 2 m	Orientation	Total imp(%)	Projection Values(m)
16				South	6.23	1
17				East	0.55	0.5
18				North	4.04	2
19				West	4.23	2
20						
21			Horizontal overlap	OVERALL THE BEST RESULTS		
22			0,15,30,45 cm	Orientation	Total imp(%)	Overlap Values(cm)
23				South	6.76	45
24				East	3.09	45
25				North	0.61	45
26				West	3.18	45
27						

Table 3: The best results for each factor for overhang shading devices

In the next step, in order to find out the best values for each factor, the best results for each factor and each direction were simulated. For instance, on south direction, predetermined most efficient factors of overhang, louvre and sidefin were simulated separately and the results were compared. This process was done for each orientation in order to create the best combinations and benefit from shading devices ideally. As can be seen from the further charts, overhang usage has a great impact with 6.34 % and 4.30 and its performance differs from others' clearly. On the other hand, on east and north directions, the louvre's performance is slightly better than the overhang. Therefore, at the end of the process, the best values of overhang were applied to south and west and the most effective values of louvre were used into north and east directions in order to get a great combination. Additionally, related charts show that sidefin shading devices do not perform very well like overhang and louvre even if their best values were simulated by gathering together.

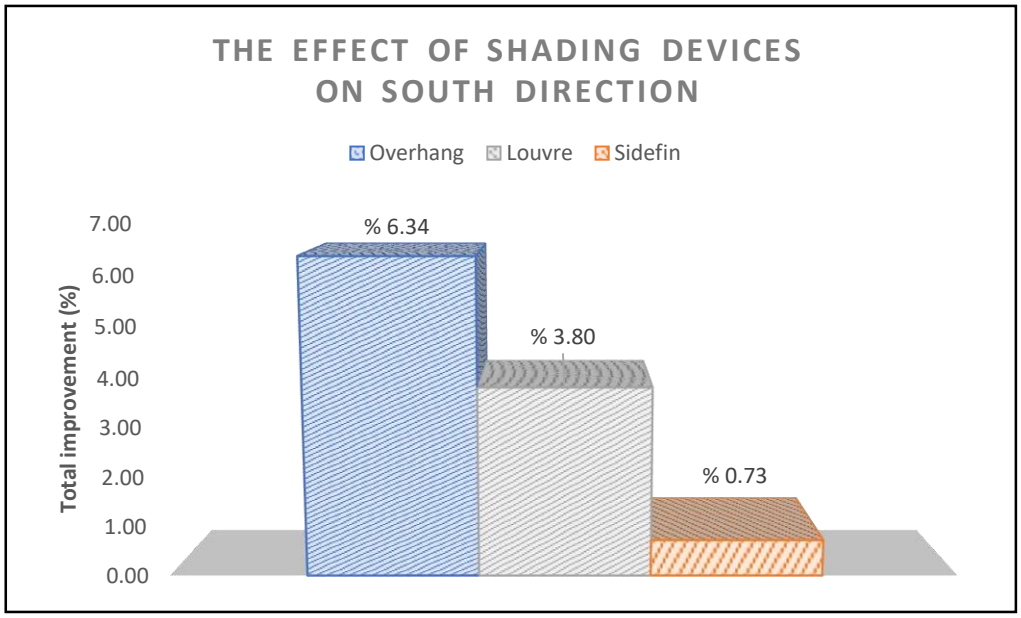


Chart 1: The effect of shading devices on south direction

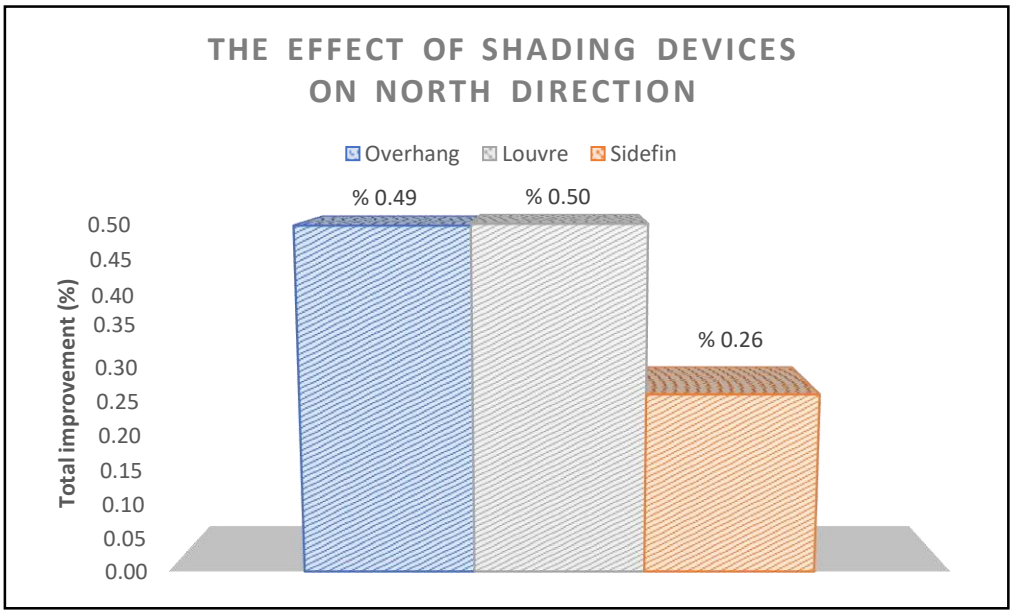


Chart 2: The effect of shading devices on south direction

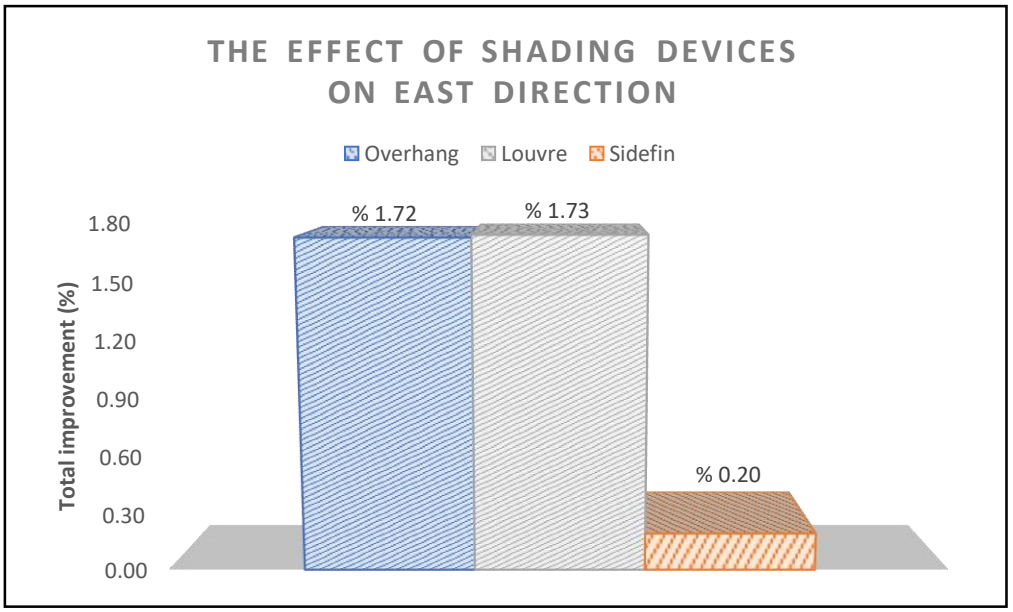


Chart 3: The effect of shading devices on south direction

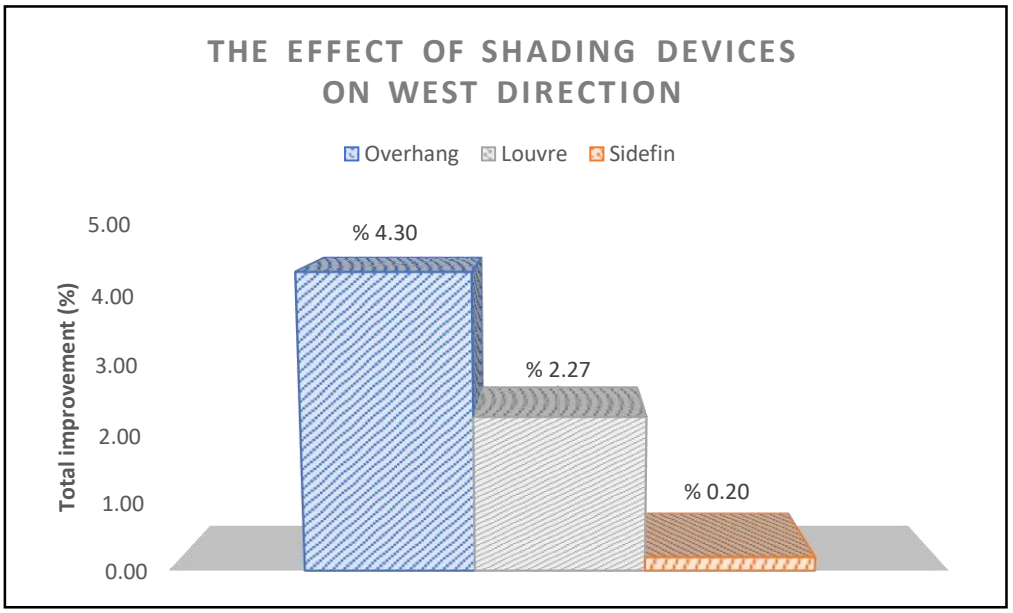


Chart 4: The effect of shading devices on south direction

At the end of all simulations, the best values were simulated on suitable orientation and overall 11.48 % of improvement was provided on cooling and lighting loads by this way. On the other hand, previously produced Table 3 shows that the most effective factors were identified for each shading type and factor. For the purpose of comparing the gathered data together, all best values for overhang, louvre and sidefin shading devices were applied to all directions separately. Chart 5 produced from all simulations' results shows that surprisingly, the application of the best factors of overhang shading devices performed better than the combination of all shadings with 12.60 % of improvement on cooling and lighting loads. Also, sidefin's low performance is remarkable with 1.39 % of improvement on energy consumption of the building as well.

Additionally, the improved floor by shading was put into top floor and ground floor and simulated in order to understand contribution differences. As can be seen in Chart 6 and Chart 7, although the improved ground and top floor provide some improvements in terms of lighting and cooling loads, their energy contribution is quite a little compared with the middle floor improvement.

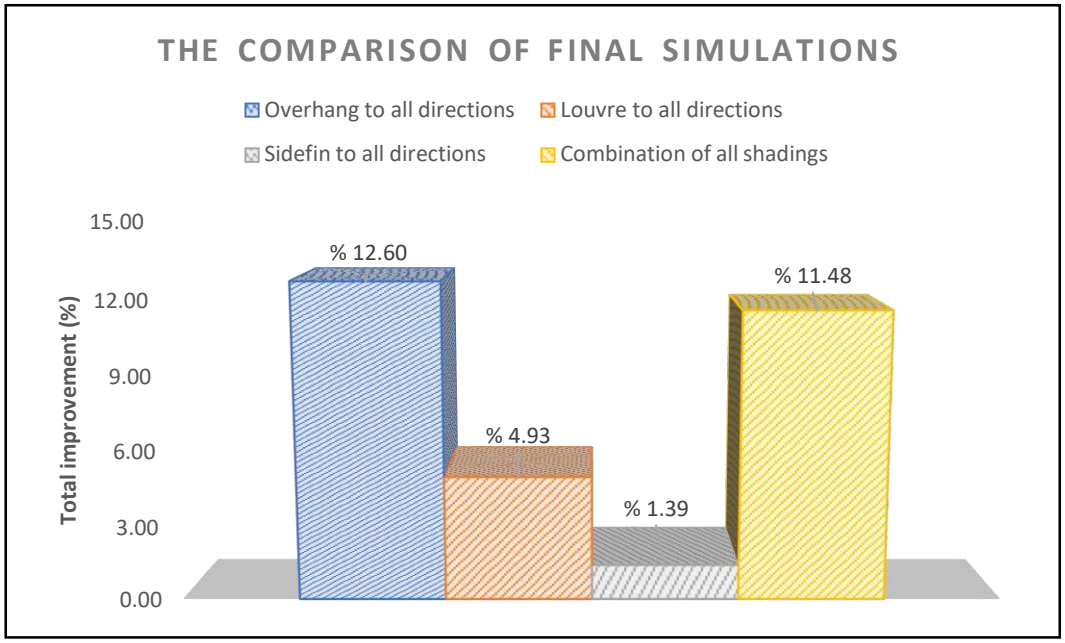


Chart 5: The comparison of overhang, louvre, sidefin and mixed simulations

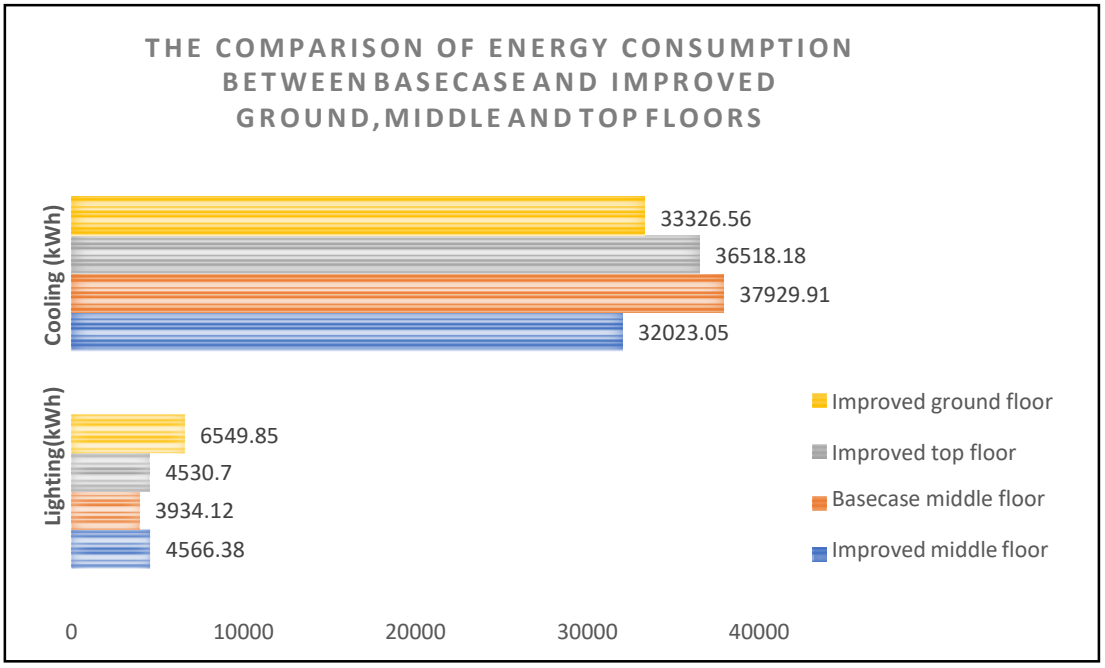


Chart 6: The comparison of base case lighting and cooling loads on the basis of floor

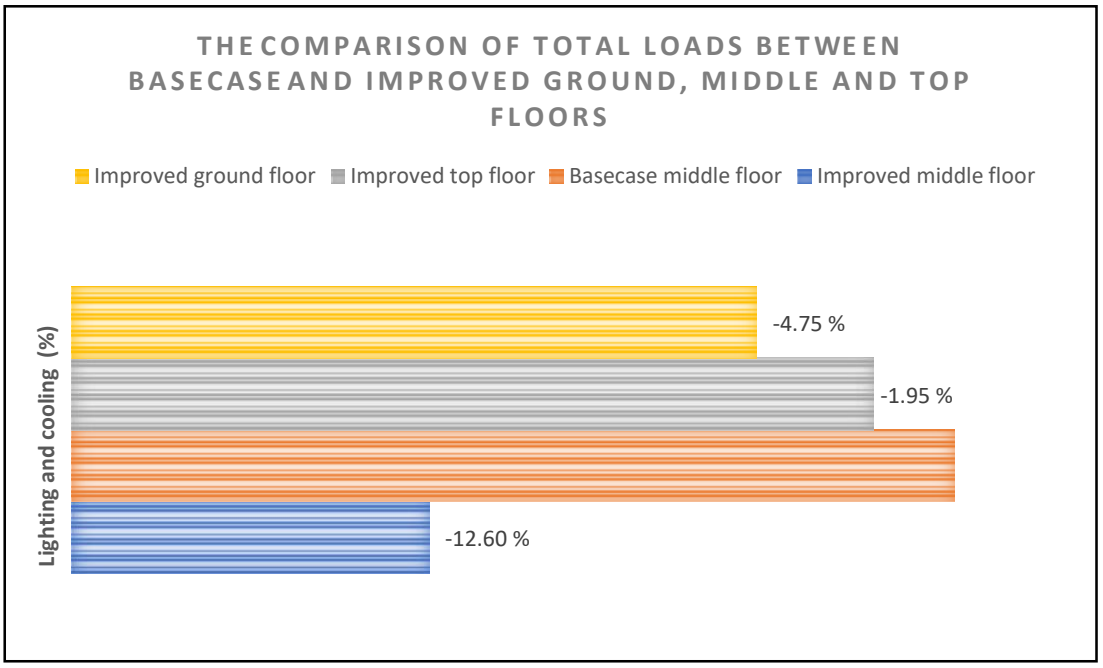


Chart 7: The comparison of base case total consumption on the basis of floor

4.4. Discussion

4.4.1. The results obtained from simulations

This study set out to assess the impact of external shading devices on cooling and lighting loads of office buildings. For this purpose, some crucial factors which have the possibility to affect the shading device performance directly were determined for specific three type of shading devices as overhang, louvre and sidefin. In order to understand the effect of the factors and increase their effectiveness on the reduction of cooling and lighting load, each factor was simulated on each orientation. At the end of these processes, the effectiveness of the factors on each direction on cooling and lighting loads and their general behavior against to changes were presented in Results section by using received data observed from simulations.

4.4.1.1. Overhang results

First of all, overhangs were analyzed on three factors as vertical offset, projection and horizontal overlap. Vertical offset has a direct relationship with the sunlight and as long as vertical offset dimensions increases and the overhang is applied to higher, gained sunlight, accordingly cooling loads increase and lighting consumption decrease as well. As can be seen in Graph 2, the most sensible orientation against to increase of vertical offset is North. Although the overhang is put more above, its solar gain increases relatively less often than other orientations due to too low sun angle because overhangs are more effective on high sun angles. The results are broadly consistent with CND studies which were mentioned in literature review section.

On the other hand, the main finding of projection factor is that the alteration of the projection factor has the least impact on North orientation similar to vertical offset's behavior. In this case, an increase of projection causes less solar gain, less cooling load but more lighting load because the projection blocks the sunlight get in more. Also, these findings concur with other studies that west and east orientations' behaviors are the same. Additionally, although the amount of solar gain received by South and West are approximately the same, their lighting consumptions differ considerably from each other while cooling consumption behaviors are showing similarity with the alteration of projection factor. This is because midday and afternoon light quality are different from each other although their solar gain and cooling loads are similar.

Besides, when horizontal overlap analysis is compared with vertical offset and projection, it can be seen that it has not considerable effects on solar gain, indirectly cooling and lighting loads. Although the most sensible orientation to solar gain is the horizontal overlap factor on south direction and North direction is not affected too much by the alteration of the factor, North direction shows more lighting requirement relatively more than others as long as horizontal overlap increases because of its low solar gain capacity from the beginning.

As can be seen in Appendix 3, although three factors of overhang have similar improvements in South direction, projection factor allows North to improve cooling and lighting loads more. Also, the improvement of energy consumption on East direction has less effect than others. Generally, the factors are effective in the reduction of energy consumption on South, West, East and North respectively.

4.4.1.2. Louvre results

Vertical shading devices were analyzed on the basis of four main factors as blade depth, vertical spacing, angle and distance from the window. As can be seen in blade depth graphs, although the least influenced orientation by the change of blade depth in terms of solar gain is North, it becomes to need a considerable amount of lighting with the increase of blade depth dimension. Also, its cooling load remains to similar amounts to other orientations but it displays opposite behavior to other directions as long as blade depth shows a rise. This is because, North is more sensible to solar gain decrease on the percentage based and for this reason, lighting load change has seen more significantly. The reason of showing opposite behavior on North is that while lighting loads are too sensitive to solar gain changes in North direction, cooling loads change slightly and because of the direct too low sun angle on North direction, the cooling load remains to increase as well by generating solar heat gain via diffuse solar radiation.

Although vertical spacing, which is one of the main factors of the louvre, causes minimum solar gain change on North direction, its increase of lighting load attracts notice by followed east similar to blade depth. Also, the increase of vertical spacing from 20 – 25 centimeter causes a rapid decline in solar gain on West direction, therefore it can be said that vertical spacing has more impact on West in terms of gaining solar heat. Additionally, although west orientation is more sensitive to solar gain with the increase of vertical spacing rather than east, as long as vertical spacing dimension increases from 20 to 35 centimeter, the cooling load of east orientation increases more than west.

On the other hand, it can be seen in Graph 16, there is a direct proportion between angle factor and solar gain and as long as the angle of the louvre increases, the solar gain decreases as well. Also, 15° can be regarded as the turning point because of the change of behaviors against to lighting and cooling loads. Also, the alteration of the angle causes the biggest percentage of cooling load increase on North surprisingly despite the least solar gain change because of having the lowest solar gain amount them.

Besides, the difference of louvre angle from 5° to 35° does not show worth considering a change in lighting load against to 11% of the increase in cooling load on south direction. Therefore, while some factors can be more effective on cooling loads, others can be more on lighting as well according to direction and factor function.

Last but not the least, distance from the window of the louvre has a significant impact on South direction prominently. As long as the distance from the window goes up, south direction shows a huge alteration with 9.4% increase in solar gain and 10.6% decrease in lighting load against to other directions showing change slightly. This factor becomes more important for South direction because it gets the light with high angle differing from other directions.

As can be seen in Appendix 3, blade depth and distance from the window are more effective factors for louvres and generally, the factors are effective in the reduction of energy consumption on South, East, West and North respectively. Also, there is very few improvement on North attracts the attention.

4.4.1.3. Sidefin results

Sidefins were analyzed on three factors as projection, horizontal offset and top and bottom overlap. As can be seen in the graphs, projection factor has a too little change as long as its increase in percentage based when compared with overhang and louvre results. Also, the most affected by projection change is South because of its allowance of getting high sun lights inside, especially in terms of lighting load.

On the other hand, horizontal offset factor of sidefin shading devices is more effective for South direction like the previous factor but as long as the factor increases, it can be seen a huge increase of solar gain and indirectly cooling load on south direction against to outstanding decrease in lighting load opposite of projection factor. While other orientations remain to stable in terms of cooling load, South shows an

appreciable decrease in lighting load because sidefins are more beneficial for South orientations due to their high solar gain possibility.

Additionally, top and bottom overlap, which define how much sidefin shading devices extend from the window alignment, do not have a great impact changing solar gain, cooling and lighting loads much. Similar to other factors of sidefin shading devices, this factor affects South's cooling and lighting loads mostly. Additionally, although west, east and north solar gains similar to each other, west orientation differentiates with the least lighting load and the most cooling load with small percentage differences. This is because, lighting in the afternoon, when the west direction gets the light more, does not provide a high quality of lighting because of low angles but it remains to get solar gain the same, therefore sidefin shading devices are not suitable for them.

As can be seen in Appendix 3, it is possible to get a slight benefit from sidefin shading devices in comparison with overhang and louvre shadings. Generally, sidefin factors are effective in the reduction of energy consumption on South, North, East and West respectively. Additionally, although approximately all overhang and louvre factors show the biggest solar gain on north direction, sidefin solar gain graphs indicate that east, west and north directions have similar potential in terms of solar gaining differing from other shading devices.

4.4.2. Selection and production of optimum results

The main research question consists of how many percentage external shading devices can reduce to cooling and lighting energy consumption of the office buildings depending on the shading type, features and applied direction. Also, research question covers whether there is a possibility to optimise the lighting and thermal comfort conditions in terms of energy efficiency and occupant satisfaction or not. For this purpose, many simulations were conducted individually, then the optimum results were selected and they were combined directional and final result based.

On the basis of direction, Chart 1,2,3 and 4 show that the best orientation to apply shading devices is South because of peak solar gain with high angles followed by West. On the other hand, North direction contributes the building at the least in terms of reduction in lighting and cooling load and this information is supported by literature review as well. Additionally, although overall most benefits are provided by overhangs, North and East directions require using louvres with the minimum difference between the overhang and louvre shading devices. Generally, they are ranked according to their contribution to reduce energy consumption as overhang, louvre and sidefin shadings respectively.

On the other hand, as can be seen in Chart 5, in order to get final results, the best values with suitable orientation were simulated in four ways as only overhang, only louvre , only sidefin on all directions and combination of all suitable shading devices on suitable directions. Overall 11.48 % of improvement on cooling and lighting loads provided by the combination of the shading devices with the best factors is an unexpected result because the application of the best factors of overhang shading devices performs better than the combination of all shadings with 12.60 % of improvement on cooling and lighting loads. Therefore, application of overhang to all directions is better than the combined one in terms of energy consumption. The reason

why the combination one gives better results than overhang one can be related to offices at the corner. These offices have two facades and such as the office facing South-East has a different type of shading devices as overhang and louvre. This is because, it can be interpreted that although these shadings give the optimum results individually, they do not perform well together at the same place due to the contradiction of their different working principles.

Additionally, as can be seen in Chart 6 and 7, although the improved ground and top floor show reduction in the cooling and lighting loads, their improvement is too little compared to the middle floor. It can be seen in the graphs, the top floor requires more cooling but less lighting, therefore the cooling and lighting requirements do not relate to the location only, it relates to the height from the ground up to floor as well.

5. Conclusion

5.1. Summary of the findings and conclusion

This paper aims to optimise cooling and lighting energy consumption in office buildings in Izmir, Turkey by using external shading devices whilst considering the future implications. As is known, the overall aim of the shading devices is to reduce unwanted heat gain and glare without reducing the daylight sufficiency in the building. Therefore, if an external shading device is designed and applied properly, it provides considerable benefits economically and ergonomically. On the other hand, all shading devices have different properties and different impacts on the thermal comfort and daylight level of the building. In this case, selection of the most suitable shading type with suitable qualifications on determined direction has become more crucial.

In this study, Izmir has selected as a potential city for overheating because of its more than 300 days potential of sun a year and sunshine duration in summer period reaches up to 12 hours. In order to reduce overheating risk, indirectly cooling consumption and increase light quality inside the building, external shading devices were used by splinting into three groups as overhang, louvre and sidefin shadings and possible effective factors of them were determined. The main conclusion of the study is 12.60% of the reduction in cooling and lighting consumption while maintaining the convenient indoor conditions for offices by conducting many simulations on the individual, directional and combinational based. Additionally, despite being located in the same building, different floors require different qualifications of shading devices. Therefore, each floor and each direction should be designed individually by considering the sun angle directions, if not it is impossible to achieve a possible improvement by shading the windows.

5.2. Recommendations for the future research

In this study, potential outcomes may present the beneficial recommendations that can be adopted and used in future studies. Additionally, the study aimed to produce a guideline for architects who are enthusiastic about designing external shading devices.

The findings obtained from the simulations concur with the literature review that shows North direction does not require solar shading because of too little solar gain but if it is an obligation for appearance, vertical shadings can be used because horizontal shadings do not block low sun angles properly. Oppositely, it is required to use overhangs for high solar gained South direction by blocking summer sun and allowing winter sun as an effective factor to reduce cooling loads. On the other hand, because of the difficulties to block sunlight in west and east, the windows can be limited on these directions.

On the other hand, further studies with statistical analyses of shading devices would be interesting. In this case, it is possible to show the behavior of all factors according to direction. Therefore, beneficial equations which include all factors for each type and each location can be given to people who decide to use external shading devices. First of all, Matlab software should be used to get random points, then space filling design as random points of combinations should be applied. For this purpose, some ranges should be determined such as external shading type, the direction of the building ranged between 0 and 360, the direction of the shading between 0 and 90, sun position parameter ranged between 0 and 180 or any specific time etc. Then, in order to get optimum points, regression lines should be used. At the end of the process, a correlation related to all factor simulated will be created and this correlation will depend on the sun height, location, climate, therefore whoever wants from any location can use it easily.

5.3. Potential limitations to the research

The main limitation of the research is taking place in only one location, Turkey, Izmir. The importance of the research , even if it is limited in location, the described design process may be implemented in all locations which have overheating problems in the buildings during warm weather and it has a potential to produce strategies or adapt to own buildings in different locations.

On the other hand, although there are not any determined overheating criteria for Turkey, CIBSE TM52 criteria were used because the criteria set are used commonly in European countries. Because of the unsuitable analysis process, the results may differ as well.

Additionally, in this study, optimisation progress was endeavored by defining some variables and values manually instead of using optimisation software tools. Therefore, optimum values were selected among identified numbers and this situation may create a limitation for the results.

Referencing List

ACE (2003) Energy efficiency in offices. Available at: http://pett-projects.org.uk/wp-content/uploads/2009/03/ACE-Research-2003-05-Energy-Efficiency-in-offices-Assessing-the-situation-report1.pdf (Accessed: 18 July 2017).

Atzeri,A. ,Pernigotto,G. ,Cappelletti,F. ,Gasparella,A. and Tzempelikos,A.(2010) 'Energy performance of shading devices for thermal and lighting comfort in offices', International Building Performance Simulation Association. Available at: http://www.ibpsa.org/proceedings/BSA2013/25.pdf (Accessed: 26 July 2017).

Autodesk (2016) Human thermal comfort. Available at: https://sustainabilityworkshop.autodesk.com/buildings/human-thermal-comfort (Accessed: 15 June 2017).

Bre (2017) Overheating in dwellings. Available at: https://www.bre.co.uk/filelibrary/Briefing%20papers/116885-Overheating-Guidance-v3.pdf (Accessed: 15 June 2017).

Buildenergy (2016) Overheating analysis. Available at: http://www.buildenergy.co.uk/dynamic-simulation-modelling/overheating-analysis/ (Accessed: 15 June 2017).

Buildingshades (2016) External and internal shades. Available at: http://bseep.weebly.com/uploads/8/0/7/2/8072374/chapter_6_external_and_internal_shades_draft_v1.pdf (Accessed: 10 August 2017).

Canadian Centre for Occupational Health and Safety (2016) Thermal comfort for office work. Available at: https://www.ccohs.ca/oshanswers/phys_agents/thermal_comfort.html (Accessed: 14 June 2017).

Carbontrust (2017) How to implement solar shading? Available at: https://www.carbontrust.com/media/19525/ctl065-how-to-implement-solar-shading.pdf (Accessed: 20 June 2017).

CIBSE (2013) The limits of thermal comfort: avoiding overheating in European Buildings. London: Chartered Institution of Building Services Engineers.

CIBSE (2014) TM49: Design Summer Years for London. Available at: http://www.cibse.org/Knowledge/knowledge-items/detail?id=a0q20000008I6yFAAS (Accessed: 12 June 2017).

CIBSE (2015) Guide A. Environmental design. 8th edn. London: Chartered Institution of Building Services Engineers.

CIBSE (2015) Guidance on preventing overheating in the home. Available at: https://www.cibse.org/getmedia/4a1e86ee-ea51-44ba-95fb-54f3165282cf/DECC-Overheating-guidance-document-19Jun2015.pdf.aspx (Accessed: 12 June 2017).

CLEAR (2014) External Shading Devices. Available at: https://www.newlearn.info/packages/clear/thermal/buildings/passive_system/solor_access_control/external_shading.html (Accessed: 25 March 2017).

Climatestotravel (2017) Climate in Izmir. Available at: http://www.climatestotravel.com/climate/turkey/izmir (Accessed: 25 June 2017).

Colorado (2015) Prediction thermal comfort. Available at: http://ceae.colorado.edu/~brandem/aren3050/docs/ThermalComfort.pdf (Accessed: 15 June 2017).

CND (2015) Carbon Neutral Design Strategies. Available at: http://tboake.com/carbon-aia/strategies1b.html (Accessed: 18 August 2017).

Designbuilder (2017) Online learning tutorials. Available at: https://www.designbuilder.co.uk/training/online-learning/tutorials (Accessed: 5 July 2017).

Duttaa,A., Samantaa,A. and Neogib,S. (2016) 'Influence of orientation and the impact of external window shading on building thermal performance in tropical climate' ,Science Direct, 139, pp.680-689.

Enrei (2016) Avoiding or minimising the use of air-conditioning. Available at: http://www.cibse.org/getmedia/6ba5d0c2-ac1a-4985-b0b5-5dc7cce359ef/GIR31-Avoiding-or-Minimising-AC.pdf.aspx (Accessed: 24 July 2017).

Freewan,A. (2014) 'Impact of external shading devices on thermal and daylighting performance of offices in hot climate regions', Science Direct, 102, pp.14-30.

Greenglobes (2017) Interior shading devices. Available at: https://www.greenglobes.com/advancedbuildings/_frames/fr_t_lighting_int_shading_devices.htm (Accessed: 11 August 2017).

Gugliermetti,F. and Bisegna,F. (2004) 'Daylighting with external shading devices: design and simulation algorithms', Science Direct, 41, pp.136-149.

Gurung,B., Shrestha,N., Dahal,P., Nakarmi,R. and Bhatta,S. (2016) Sun shading devices. Available at: https://www.slideshare.net/prabaldahal/sun-shading-devices (Accessed: 13 August 2017).

IES (2016) CIBSE TM52: Comfort analysis. Available at: http://www.iesve.com/downloads/help/VE2014/Thermal/VistaPro_CIBSETM52_AdaptiveComfort.pdf (Accessed: 25 June 2017).

IPCC (2015) Residential and commercial buildings. Available at: https://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter6.pdf (Accessed: 25 March 2017).

Iyengar,K. (2015) Sustainable Architectural Design: An Overview. Available at: https://books.google.co.uk/books?id=z7RhCQAAQBAJ&pg=PA36&lpg=PA36&dq=Special+care+should+be+taken+to+shade+the+windows+to+reduce+the+incoming+heat+and+the+risk+of+overheating.&source=bl&ots=Qhm_eBLrM8&sig=gLDn3Z6UixybPET7L9kj81RtTHQ&hl=en&sa=X&ved=0ahUKEwiTmazW8fHSAhVMCMAKHf4rCCgQ6AEIHTAB#v=onepage&q=Special%20care%20should%20be%20taken%20to%20shade%20the%20windows%20to%20reduce%20the%20incoming%20heat%20and%20the%20risk%20of%20overheating.&f=false (Accessed: 22 March 2017).

Jensen (2016) How Office Lighting Affects Productivity. Available at: http://www.andrewjensen.net/how-office-lighting-affects-productivity/ (Accessed: 19 July 2017).

Kaita, M. and Alibaba, H. (2017) 'Shading Devices in High Rise Buildings in the Tropics', International Journal of Recent Research in Civil and Mechanical Engineering, 3(2), pp.37-46.

Kellwood (2016) CIBSE recommended lux levels. Available at: https://www.kellwood.co.uk/led-lighting/technical/cibse-recommended-lux-levels (Accessed: 13 July 2017).

Lomas,K. and Porritt,S. (2016) Overheating in buildings: lessons from research. Available at: http://www.tandfonline.com/doi/full/10.1080/09613218.2017.1256136 (Accessed: 18 June 2017).

Nicol,F. (2016) TM52 The limits of thermal comfort: avoiding overheating in European buildings. Available at: http://www.cibse.org/getattachment/Networks/Regions/South-Wales/South-Wales-Past-Presentations/TM52-The-limits-of-thermal-comfort-Cardiff.pdf.aspx (Accessed: 26 June 2017).

NZEB (2016) Shading. Available at: http://www.nzeb.in/knowledge-centre/passive-design/shading/ (Accessed: 12 July 2017).

PUD (2016) Managing Energy Costs in Large Office Buildings. Available at: https://snopud.bizenergyadvisor.com/large-offices (Accessed: 24 July 2017).

Roche L., Dewey E. and Littlefair P. (2000) Occupant reactions to daylight in offices. Available at: http://journals.sagepub.com/doi/abs/10.1177/096032710003200303 (Accessed: 18 July 2017).

Sousa, J. (2016) Energy Simulation Software for Buildings: Review and Comparison. Available at: http://ceur-ws.org/Vol-923/paper08.pdf (Accessed: 14 August 2017).

Strathclyde University (2016) Passive Design. Available at: http://www.esru.strath.ac.uk/EandE/Web_sites/09-10/Hybrid_systems/passivedesign.pdf (Accessed: 25 March 2017).

WBDG (2017) Sun control and shading devices. Available at: https://www.wbdg.org/resources/sun-control-and-shading-devices (Accessed: 15 July 2017).

WSPS (2011) Office workstation design. Available at: http://www.kghwellness.ca/sites/kghwellness.ca/files/Office_Workstation_Design_AUG2013.pdf (Accessed: 13 July 2017).

Ye,Y., Xu,P. ,Mao, J. and Ji,Y. (2016) 'Experimental study on the effectiveness of internal shading devices', Journal of Energy and Buildings,111, pp.154-163.

Zerocarbonhub (2016) Impacts of overheating. Available at: http://www.zerocarbonhub.org/sites/default/files/resources/reports/ZCH-OverheatingEvidenceReview-Impacts.pdf (Accessed: 13 June 2017).

Appendices

Appendix 1: All results obtained from simulations as excel sheets

1.1. Overhang Results

BASE CASE	Solar gain(kWh)	Operative temp(°C)	Relative humitidy(%)	Daylight factor(%)	Lighting load(kWh)	Cooling load(kWh)
	29895.59	26.17	45.09	2.122	3934.12	37929.91

	Vertical offset(cm)	Solar gain(kWh)	Operative temp(°C)	Relative humitidy(%)	Daylight factor(%)	Lighting load(kWh)	Cooling load(kWh)
South	0	24432.56	25.86	45.75	1.841	4028.35	35379.69
	10	24764.04	25.88	45.72	1.878	4013.16	35513.72
	20	25023.3	25.89	45.69	1.911	4010.67	35622.57
	30	25273.53	25.9	45.66	1.937	3987.15	35718.57
East	0	27394.9	26.03	45.37	1.983	3975.53	36699.35
	10	27696.94	26.05	45.33	2.007	3969.4	36840.32
	20	27962.07	26.07	45.31	2.02	3967.96	36968.04
	30	28210.25	26.08	45.28	2.04	3954.87	37082.3
North	0	28813.01	26.12	45.2	1.832	4104.61	37539.04
	10	29008.91	26.13	45.18	1.86	4090.16	37621.18
	20	29131.78	26.14	45.17	1.893	4085.65	37673.18
	30	29233.82	26.14	45.16	1.929	4014.51	37680.82
West	0	27248.17	26.01	45.45	1.983	3983.49	36653.81
	10	27568.24	26.03	45.4	1.992	3976.24	36799.98
	20	27851.76	26.04	45.37	2.011	3975.62	36936.46
	30	28116.81	26.06	45.33	2.029	3961.41	37054.93

	Projection(m)	Solar gain(kWh)	Operative temp(°C)	Relative humitidy(%)	Daylight factor(%)	Lighting load(kWh)	Cooling load(kWh)
South	0.5	25969.92	25.95	45.56	1.954	3965.7	36058.54
	1	24432.56	25.86	45.75	1.843	4028.35	35379.69
	1.5	24092.48	25.85	45.77	1.779	4285.8	35358.84
	2	23916.67	25.84	45.79	1.746	4287.07	35290.5
East	0.5	28469.13	26.09	45.25	2.039	3947.42	37228.25
	1	27394.9	26.03	45.37	1.986	3975.53	36699.35
	1.5	26732.59	25.99	45.46	1.953	4015.68	36411.77
	2	26335.51	25.97	45.51	1.943	4018.29	36219.5
North	0.5	29249.11	26.14	45.17	1.948	3974.11	37660.85
	1	28813.01	26.12	45.2	1.837	4104.61	37539.04
	1.5	28540.96	26.11	45.22	1.762	4265.86	37506.93
	2	28332.27	26.1	45.25	1.721	4279.01	37420.93
West	0.5	28391.39	26.08	45.29	2.035	3950.27	37195.08
	1	27248.17	26.01	45.45	1.98	3983.49	36653.81
	1.5	26537.13	25.96	45.55	1.948	4029.96	36337.08
	2	26108.07	25.93	45.62	1.926	4031.56	36135.02

	Horizontal overlap(cm)	Solar gain(kWh)	Operative temp(°C)	Relative humitidy(%)	Daylight factor(%)	Lighting load(kWh)	Cooling load(kWh)
South	0	24432.56	25.86	45.75	1.843	4028.35	35379.69
	15	24245.5	25.85	45.78	1.827	4028.72	35289.84
	30	24118.85	25.84	45.8	1.827	4029.38	35227.35
	45	24029.47	25.84	45.82	1.827	4029.93	35181.63
East	0	27394.9	26.03	45.37	1.985	3975.53	36699.35
	15	27325.77	26.03	45.38	1.977	3975.54	36665.06
	30	27289.02	26.03	45.38	1.984	3975.54	36646.42
	45	27268.62	26.03	45.39	1.977	3975.54	36635.57
North	0	28813.01	26.12	45.2	1.824	4104.61	37539.04
	15	28775.81	26.12	45.21	1.822	4106.85	37523.62
	30	28748.69	26.12	45.21	1.823	4107.56	37511.39
	45	28726.78	26.11	45.21	1.812	4109.72	37502.23
West	0	27248.17	26.01	45.45	1.978	3983.49	36653.81
	15	27177.79	26	45.46	1.973	3983.51	36619.79
	30	27140.39	26	45.46	1.972	3983.52	36601.18
	45	27119.68	26	45.47	1.968	3983.52	36590.39

1.2. Louvre Results

SOUTH	*Blade depth(cm)*	Solar gain(kWh)	Operative temp(°C)	Relative humitidy(%)	Daylight factor(%)	Lighting load(kWh)	Cooling load(kWh)
	15	26738.94	26	45.45	1.9	4029.23	36516.32
	20	26334.93	25.98	45.49	1.827	4060.16	36357.08
	25	26134.27	25.97	45.51	1.787	4167.6	36329.32
	30	25968.38	25.96	45.52	1.746	4191.18	36274.43
EAST	15	28002.73	26.07	45.3	2.015	3975.29	37023.52
	20	27526.06	26.04	45.36	1.983	3995.05	36801.82
	25	27157.29	26.02	45.4	1.957	4047.26	36648.29
	30	26872.29	26	45.43	1.936	4058.07	36516.55
NORTH	15	28985.08	26.13	45.19	1.896	4088.37	37601.81
	20	28748.54	26.12	45.19	1.831	4314.15	37614.41
	25	28550.56	26.12	45.18	1.768	4662.67	37710.86
	30	28378.38	26.13	45.16	1.741	5351.98	37991.01
WEST	15	27887.08	26.05	45.36	2.001	3983.19	36978.63
	20	27378.59	26.01	45.43	1.973	3998.79	36740.73
	25	26983.73	25.99	45.48	1.944	4060.37	36585.41
	30	26676.75	25.97	45.53	1.932	4073.58	36448.7

SOUTH	*Vertical spacing(cm)*	Solar gain(kWh)	Operative temp(°C)	Relative humitidy(%)	Daylight factor(%)	Lighting load(kWh)	Cooling load(kWh)
	20	26476.88	25.99	45.46	1.832	4304.9	36539.5
	25	26330.53	25.99	45.47	1.822	4354.1	36493.44
	30	26334.93	25.98	45.49	1.822	4060.16	36357.08
	35	26460.63	25.99	45.45	1.854	4428.72	36584.06
EAST	**20**	27640.08	26.05	45.34	1.976	4010.28	36867.11
	25	27528.59	26.04	45.36	1.972	4013.91	36812.54
	30	27526.06	26.04	45.36	1.98	3995.05	36801.82
	35	27636.63	26.05	45.32	1.992	4273.3	36990.54
NORTH	**20**	28784.08	26.13	45.18	1.828	4405.41	37677.82
	25	28748.1	26.12	45.2	1.809	4258.01	37587.17
	30	28748.54	26.12	45.19	1.827	4314.15	37614.41
	35	28784.61	26.14	45.13	1.853	4953.81	37974.94
WEST	**20**	27948.62	26.02	45.41	1.961	4014.82	36808.62
	25	27381.94	26.02	45.43	1.962	4034.29	36760.94
	30	27378.59	26.01	45.43	1.979	3998.79	36740.73
	35	27495.08	26.03	45.4	1.989	4185.38	36890.97

SOUTH	*Angle(°)*	Solar gain(kWh)	Operative temp(°C)	Relative humitidy(%)	Daylight factor(%)	Lighting load(kWh)	Cooling load(kWh)
	5	26577.84	25.99	45.47	1.882	4021.27	36436.18
	15	26334.93	25.98	45.49	1.838	4060.16	36357.08
	25	26139.21	25.97	45.5	1.79	4167.4	36330.77
	35	25977.94	25.97	45.5	1.754	4564.72	36458.09
EAST	**5**	27856.08	26.06	45.32	2.007	3973.09	36948.87
	15	27526.06	26.04	45.36	1.937	3995.05	36801.82
	25	27260.29	26.03	45.38	1.958	4047.47	36700.45
	35	27052.78	26.02	45.39	1.943	4406.92	36782.47
NORTH	**5**	28970.63	26.13	45.19	1.877	4080.25	37593.93
	15	28748.54	26.12	45.19	1.823	4314.15	37614.41
	25	28555.44	26.12	45.18	1.781	4662.41	37710.66
	35	28392.85	26.14	45.11	1.749	5693.08	38183.71
WEST	**5**	27730.97	26.04	45.38	2.001	3979.99	36889.39
	15	27378.59	26.01	45.43	1.972	3998.79	36740.73
	25	27094.71	26	45.47	1.949	4060.71	36639
	35	26873.74	25.99	45.48	1.934	4320.32	36667.52

SOUTH	*Distance from window(cm)*	Solar gain(kWh)	Operative temp(°C)	Relative humitidy(%)	Daylight factor(%)	Lighting load(kWh)	Cooling load(kWh)
	10	24575.25	25.89	45.68	1.76	4537.79	35734.97
	20	25440.75	25.94	45.58	1.793	4488.15	36128.21
	30	26334.93	25.98	45.49	1.841	4060.16	36357.08
	40	27135.47	26.02	45.39	1.871	4102.13	36758.87
EAST	**10**	27153.33	26.02	45.39	1.936	4042.24	36623.65
	20	27321.93	26.03	45.38	1.951	4040.16	36722.87
	30	27526.06	26.04	45.36	1.975	3995.05	36801.82
	40	27739.76	26.05	45.33	2.001	4014.33	36915.88
NORTH	**10**	28540.57	26.11	45.22	1.752	4309.95	37522.79
	20	28642.01	26.12	45.2	1.793	4328.29	37578.24
	30	28748.54	26.12	45.19	1.822	4314.15	37614.41
	40	28852.08	26.13	45.17	1.862	4454.84	37736.14
WEST	**10**	26993.26	25.99	45.48	1.941	4061.62	36584.46
	20	27167.37	26	45.46	1.955	4045.02	36661.16
	30	27378.59	26.01	45.43	1.979	3998.79	36740.73
	40	27601.93	26.03	45.4	1.986	4021.18	36861

1.3. Sidefin Results

	Projection(cm)	Solar gain(kWh)	Operative temp(°C)	Relative humitidy(%)	Daylight factor(%)	Lighting load(kWh)	Cooling load(kWh)
South	30	29387.34	26.14	45.16	2.11	3937.28	37689.89
	40	29261.91	26.13	45.17	2.092	3953.25	37639.99
	50	29160.38	26.13	45.18	2.092	3957	37596.26
	60	29076.23	26.12	45.19	2.086	3960.22	37560.22
East	30	29745.69	26.16	45.11	2.114	3934.4	37860.26
	40	29694.42	26.16	45.12	2.106	3934.42	37836.47
	50	29647.96	26.16	45.12	2.1	3934.43	37815
	60	29606.09	26.15	45.13	2.111	3936.91	37796.75
North	30	29693.55	26.16	45.12	2.113	3938.89	37831.81
	40	29633.05	26.15	45.13	2.1	3939.64	37801.45
	50	29577.1	26.15	45.13	2.097	3940.31	37774.45
	60	29524.24	26.15	45.14	2.094	3942.34	37749.94
West	30	29744.02	26.16	45.11	2.115	3934.42	37857.44
	40	29692.23	26.16	45.12	2.11	3934.45	37833.25
	50	29645.28	26.15	45.12	2.103	3934.48	37811.59
	60	29602.91	26.15	45.13	2.105	3937.1	37793.19

	Horizontal offset(cm)	Solar gain(kWh)	Operative temp(°C)	Relative humitidy(%)	Daylight factor(%)	Lighting load(kWh)	Cooling load(kWh)
South	0	29160.38	26.13	45.18	2.094	3957	37596.26
	10	29340.38	26.14	45.16	2.103	3953.92	37674.37
	20	29470.98	26.14	45.15	2.114	3943.77	37729.41
	30	29570.23	26.15	45.14	2.119	3937.39	37770.57
East	0	29647.96	26.16	45.12	2.106	3934.43	37815
	10	29738.57	26.16	45.11	2.114	3934.39	37857.51
	20	29787.52	26.16	45.11	2.113	3934.39	37879.95
	30	29818.32	26.16	45.1	2.116	3934.39	37893.78
North	0	29577.1	26.15	45.13	2.102	3940.31	37774.45
	10	29641.94	26.15	45.13	2.105	3940.07	37806.12
	20	29685.15	26.16	45.12	2.119	3939.84	37826.19
	30	29719.78	26.16	45.12	2.12	3939.61	37842.16
West	0	29645.28	26.15	45.12	2.102	3934.48	37811.59
	10	29737.08	26.16	45.11	2.117	3934.4	37854.24
	20	29787.1	26.16	45.11	2.112	3934.4	37877.33
	30	29818.04	26.16	45.1	2.117	3934.4	37891.52

	Top and bottom overlap(cm)	Solar gain(kWh)	Operative temp(°C)	Relative humitidy(%)	Daylight factor(%)	Lighting load(kWh)	Cooling load(kWh)
South	0	29160.38	26.13	45.18	2.09	3957	37596.26
	10	29096.29	26.12	45.19	2.092	3958.75	37565.73
	20	29041.53	26.12	45.2	2.092	3958.92	37538.3
	30	28994.12	26.12	45.2	2.086	3959.51	37513.66
East	0	29647.96	26.16	45.12	2.109	3934.43	37815
	10	29631.05	26.15	45.12	2.108	3934.44	37806.75
	20	29618.46	26.15	45.12	2.103	3934.62	37800.57
	30	29608.89	26.15	45.13	2.109	3934.62	37795.66
North	0	29577.1	26.15	45.13	2.097	3940.31	37774.45
	10	29558.07	26.15	45.14	2.096	3940.62	37764.92
	20	29544.67	26.15	45.14	2.097	3940.86	37758.03
	30	29534.61	26.15	45.14	2.098	3941.41	37752.89
West	0	29645.28	26.15	45.12	2.108	3934.48	37811.59
	10	29628.16	26.15	45.13	2.106	3934.48	37803.27
	20	29615.4	26.15	45.13	2.11	3934.68	37797.01
	30	29605.7	26.15	45.13	2.105	3934.68	37792.07

Appendix 2 : The selection process of the best results as excel sheets

2.1. Projection factor of the overhang shading devices

Orientation	Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)	Lighting imp(%)	Cooling imp(%)	Total imp(%)
SOUTH	3965.7	36058.54	40024.24	-0.80	4.93	4.60
	4028.35	35379.69	39408.04	-2.40	6.72	6.23
	4285.8	35358.84	39644.64	-8.94	6.78	5.60
	4287.07	35290.5	39577.57	-8.97	6.96	5.78
EAST	3974.11	37660.85	41634.96	-1.02	0.71	0.55
	4104.61	37539.04	41643.65	-4.33	1.03	0.53
	4265.86	37506.93	41772.79	-8.43	1.12	0.22
	4279.01	37420.93	41699.94	-8.77	1.34	0.39
NORTH	3947.42	37228.25	41175.67	-0.34	1.85	1.67
	3975.53	36699.35	40674.88	-1.05	3.24	2.92
	4015.68	36411.77	40427.45	-2.07	4.00	3.55
	4018.29	36219.5	40237.79	-2.14	4.51	4.04
WEST	3950.27	37195.08	41145.35	-0.41	1.94	1.75
	3983.49	36653.81	40637.3	-1.25	3.36	3.02
	4029.96	36337.08	40367.04	-2.44	4.20	3.71
	4031.56	36135.02	40166.58	-2.48	4.73	4.23

BASE CASE RESULTS		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3934.12	37929.91	41864.03

OVERALL THE BEST RESULTS		
Orientation	Total imp(%)	Projection Values(m)
South	6.23	1
East	0.55	0.5
North	4.04	2
West	4.23	2

2.2. Vertical offset factor of the overhang shading devices

Orientation	Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)	Lighting imp(%)	Cooling imp(%)	Total imp(%)
SOUTH	4028.35	35379.69	39408.04	-2.40	6.72	6.23
	4013.16	35513.72	39526.88	-2.01	6.37	5.91
	4010.67	35622.57	39633.24	-1.95	6.08	5.63
	3987.15	35718.57	39705.72	-1.35	5.83	5.44
EAST	3975.53	36699.35	40674.88	-1.05	3.24	2.92
	3969.4	36840.32	40809.72	-0.90	2.87	2.58
	3967.96	36968.04	40936	-0.86	2.54	2.27
	3954.87	37082.3	41037.17	-0.53	2.23	2.01
NORTH	4104.61	37539.04	41643.65	-4.33	1.03	0.53
	4090.16	37621.18	41711.34	-3.97	0.81	0.37
	4085.65	37673.18	41758.83	-3.85	0.68	0.25
	4014.51	37680.82	41695.33	-2.04	0.66	0.40
WEST	3983.49	36653.81	40637.3	-1.25	3.36	3.02
	3976.24	36799.98	40776.22	-1.07	2.98	2.67
	3975.62	36936.46	40912.08	-1.05	2.62	2.33
	3961.41	37054.93	41016.34	-0.69	2.31	2.07

BASE CASE RESULTS		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3934.12	37929.91	41864.03

OVERALL THE BEST RESULTS		
Orientation	Total imp(%)	Vertical Values(cm)
South	6.23	0
East	2.92	0
North	0.53	0
West	3.02	0

2.3. Projection factor of the overhang shading devices

Orientation	Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)	Lighting imp(%)	Cooling imp(%)	Total imp(%)
SOUTH	4028.35	35379.69	39408.04	-2.40	6.72	6.23
	4028.72	35289.84	39318.56	-2.40	6.96	6.47
	4029.38	35227.35	39256.73	-2.42	7.13	6.64
	4029.93	35181.63	39211.56	-2.44	7.25	6.76
EAST	3975.53	36699.35	40674.88	-1.05	3.24	2.92
	3975.54	36665.06	40640.6	-1.05	3.33	3.01
	3975.54	36646.42	40621.96	-1.05	3.38	3.06
	3975.54	36635.57	40611.11	-1.05	3.41	3.09
NORTH	4104.61	37539.04	41643.65	-4.33	1.03	0.53
	4106.85	37523.62	41630.47	-4.39	1.07	0.56
	4107.56	37511.39	41618.95	-4.41	1.10	0.59
	4109.72	37502.23	41611.95	-4.46	1.13	0.61
WEST	3983.49	36653.81	40637.3	-1.25	3.36	3.02
	3983.51	36619.79	40603.3	-1.26	3.45	3.10
	3983.52	36601.18	40584.7	-1.26	3.50	3.15
	3983.52	36590.39	40573.91	-1.26	3.53	3.18

BASE CASE RESULTS		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3934.12	37929.91	41864.03

OVERALL THE BEST RESULTS		
Orientation	Total imp(%)	Overlap Values(cm)
South	6.76	45
East	3.09	45
North	0.61	45
West	3.18	45

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2.4. Angle factor of the louvre shading devices

Orientation	Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)	Lighting imp(%)	Cooling imp(%)	Total imp(%)
SOUTH	4021.27	36436.18	40457.45	-2.22	3.94	3.48
	4060.16	36357.08	40417.24	-3.20	4.15	3.58
	4167.4	36330.77	40498.17	-5.93	4.22	3.37
	4564.72	36458.09	41022.81	-16.03	3.88	2.05
EAST	3973.09	36948.87	40921.96	-0.99	2.59	2.30
	3995.05	36801.82	40796.87	-1.55	2.97	2.62
	4047.47	36700.45	40747.92	-2.88	3.24	2.74
	4406.92	36782.47	41189.39	-12.02	3.03	1.64
NORTH	4080.25	37593.93	41674.18	-3.71	0.89	0.46
	4314.15	37614.41	41928.56	-9.66	0.83	-0.15
	4662.41	37710.66	42373.07	-18.51	0.58	-1.20
	5693.08	38183.71	43876.79	-44.71	-0.67	-4.59
WEST	3979.99	36889.39	40869.38	-1.17	2.74	2.43
	3998.79	36740.73	40739.52	-1.64	3.14	2.76
	4060.71	36639	40699.71	-3.22	3.40	2.86
	4320.32	36667.52	40987.84	-9.82	3.33	2.14

BASE CASE RESULTS		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3934.12	37929.91	41864.03

OVERALL THE BEST RESULTS		
Orientation	Total imp(%)	Angle Values(°)
South	3.58	15
East	2.74	25
North	0.46	5
West	2.86	25

2.5. Blade depth factor of the louvre shading devices

Orientation	Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)	Lighting imp(%)	Cooling imp(%)	Total imp(%)
SOUTH	4029.23	36516.32	40545.55	-2.42	3.73	3.25
	4060.16	36357.08	40417.24	-3.20	4.15	3.58
	4167.6	36329.32	40496.92	-5.93	4.22	3.38
	4191.18	36274.43	40465.61	-6.53	4.36	3.46
EAST	3975.29	37023.52	40998.81	-1.05	2.39	2.11
	3995.05	36801.82	40796.87	-1.55	2.97	2.62
	4047.26	36648.29	40695.55	-2.88	3.38	2.87
	4058.07	36516.55	40574.62	-3.15	3.73	3.18
NORTH	4088.37	37601.81	41690.18	-3.92	0.87	0.42
	4314.15	37614.41	41928.56	-9.66	0.83	-0.15
	4662.67	37710.86	42373.53	-18.52	0.58	-1.20
	5351.98	37991.01	43342.99	-36.04	-0.16	-3.41
WEST	3983.19	36978.63	40961.82	-1.25	2.51	2.20
	3998.79	36740.73	40739.52	-1.64	3.14	2.76
	4060.37	36585.41	40645.78	-3.21	3.54	3.00
	4073.58	36448.7	40522.28	-3.54	3.91	3.31

BASE CASE RESULTS		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3934.12	37929.91	41864.03

OVERALL THE BEST RESULTS		
Orientation	Total imp(%)	Depth Values(cm)
South	3.58	20
East	3.18	30
North	0.42	15
West	3.31	30

2.6. Distance from window of the louvre shading devices

Orientation	Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)	Lighting imp(%)	Cooling imp(%)	Total imp(%)
SOUTH	4537.79	35734.97	40272.76	-15.34	5.79	3.95
	4488.15	36128.21	40616.36	-14.08	4.75	3.07
	4060.16	36357.08	40417.24	-3.20	4.15	3.58
	4102.13	36758.87	40861	-4.27	3.09	2.45
EAST	4042.24	36623.65	40665.89	-2.75	3.44	2.95
	4040.16	36722.87	40763.03	-2.70	3.18	2.70
	3995.05	36801.82	40796.87	-1.55	2.97	2.62
	4014.33	36915.88	40930.21	-2.04	2.67	2.28
NORTH	4309.95	37522.79	41832.74	-9.55	1.07	0.07
	4328.29	37578.24	41906.53	-10.02	0.93	-0.10
	4314.15	37614.41	41928.56	-9.66	0.83	-0.15
	4454.84	37736.14	42190.98	-13.24	0.51	-0.77
WEST	4061.62	36584.46	40646.08	-3.24	3.55	3.00
	4045.02	36661.16	40706.18	-2.82	3.34	2.84
	3998.79	36740.73	40739.52	-1.64	3.14	2.76
	4021.18	36861	40882.18	-2.21	2.82	2.40

BASE CASE RESULTS		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3934.12	37929.91	41864.03

OVERALL THE BEST RESULTS		
Orientation	Total imp(%)	Distance Values(cm)
South	3.95	10
East	2.95	10
North	0.07	10
West	3	10

Sheet1

2.7. Vertical spacing of the louvre shading devices

Orientation	Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)	Lighting imp(%)	Cooling imp(%)	Total imp(%)
SOUTH	4304.9	36539.5	40844.4	-9.42	3.67	2.50
	4354.1	36493.44	40847.54	-10.68	3.79	2.49
	4060.16	36357.08	40417.24	-3.20	4.15	3.58
	4428.72	36584.06	41012.78	-12.57	3.55	2.08
EAST	4010.28	36867.11	40877.39	-1.94	2.80	2.41
	4013.91	36812.54	40826.45	-2.03	2.95	2.54
	3995.05	36801.82	40796.87	-1.55	2.97	2.62
	4273.3	36990.54	41263.84	-8.62	2.48	1.45
NORTH	4405.41	37677.82	42083.23	-11.98	0.66	-0.52
	4258.01	37587.17	41845.18	-8.23	0.90	0.05
	4314.15	37614.41	41928.56	-9.66	0.83	-0.15
	4953.81	37974.94	42928.75	-25.92	-0.12	-2.48
WEST	4014.82	36808.62	40823.44	-2.05	2.96	2.55
	4034.29	36760.94	40795.23	-2.55	3.08	2.62
	3998.79	36740.73	40739.52	-1.64	3.14	2.76
	4185.38	36890.97	41076.35	-6.39	2.74	1.92

BASE CASE RESULTS		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3934.12	37929.91	41864.03

OVERALL THE BEST RESULTS		
Orientation	Total imp(%)	Vertical Values(cm)
South	3.58	30
East	2.62	30
North	0.05	25
West	2.76	30

2.8. Horizontal offset of the sidefin shading devices

Orientation	Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)	Lighting imp(%)	Cooling imp(%)	Total imp(%)
SOUTH	3957	37596.26	41553.26	-0.58	0.88	0.75
	3953.92	37674.37	41628.29	-0.50	0.67	0.57
	3943.77	37729.41	41673.18	-0.25	0.53	0.46
	3937.39	37770.57	41707.96	-0.08	0.42	0.37
EAST	3934.43	37815	41749.43	-0.01	0.30	0.27
	3934.39	37857.51	41791.9	-0.01	0.19	0.17
	3934.39	37879.95	41814.34	-0.01	0.13	0.12
	3934.39	37893.78	41828.17	-0.01	0.10	0.09
NORTH	3940.31	37774.45	41714.76	-0.16	0.41	0.36
	3940.07	37806.12	41746.19	-0.15	0.33	0.28
	3939.84	37826.19	41766.03	-0.15	0.27	0.23
	3939.61	37842.16	41781.77	-0.14	0.23	0.20
WEST	3934.48	37811.59	41746.07	-0.01	0.31	0.28
	3934.4	37854.24	41788.64	-0.01	0.20	0.18
	3934.4	37877.33	41811.73	-0.01	0.14	0.13
	3934.4	37891.52	41825.92	-0.01	0.10	0.09

BASE CASE RESULTS		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3934.12	37929.91	41864.03

OVERALL THE BEST RESULTS		
Orientation	Total imp(%)	Horizontal Values(cm)
South	0.75	0
East	0.27	0
North	0.36	0
West	0.28	0

2.9. Top and bottom overlap of the sidefin shading devices

Orientation	Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)	Lighting imp(%)	Cooling imp(%)	Total imp(%)
SOUTH	3957	37596.26	41553.26	-0.58	0.88	0.75
	3958.75	37565.73	41524.48	-0.63	0.96	0.82
	3958.92	37538.3	41497.22	-0.63	1.03	0.88
	3959.51	37513.66	41473.17	-0.65	1.10	0.94
EAST	3934.43	37815	41749.43	-0.01	0.30	0.27
	3934.44	37806.75	41741.19	-0.01	0.32	0.29
	3934.62	37800.57	41735.19	-0.01	0.34	0.31
	3934.62	37795.66	41730.28	-0.01	0.35	0.32
NORTH	3940.31	37774.45	41714.76	-0.16	0.41	0.36
	3940.62	37764.92	41705.54	-0.17	0.43	0.38
	3940.86	37758.03	41698.89	-0.17	0.45	0.40
	3941.41	37752.89	41694.3	-0.19	0.47	0.41
WEST	3934.48	37811.59	41746.07	-0.01	0.31	0.28
	3934.48	37803.27	41737.75	-0.01	0.33	0.30
	3934.68	37797.01	41731.69	-0.01	0.35	0.32
	3934.68	37792.07	41726.75	-0.01	0.36	0.33

BASE CASE RESULTS		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3934.12	37929.91	41864.03

OVERALL THE BEST RESULTS		
Orientation	Total imp(%)	Overlap Values(cm)
South	0.94	30
East	0.32	30
North	0.41	30
West	0.33	30

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2.10. Projection of the sidefin shading devices

Orientation	Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)	Lighting imp(%)	Cooling imp(%)	Total imp(%)
SOUTH	3937.28	37689.89	41627.17	-0.08	0.63	0.57
	3953.25	37639.99	41593.24	-0.49	0.76	0.65
	3957	37596.26	41553.26	-0.58	0.88	0.75
	3960.22	37560.22	41520.44	-0.66	0.97	0.83
EAST	3934.4	37860.26	41794.66	-0.01	0.18	0.17
	3934.42	37836.47	41770.89	-0.01	0.25	0.22
	3934.43	37815	41749.43	-0.01	0.30	0.27
	3936.91	37796.75	41733.66	-0.07	0.35	0.31
NORTH	3938.89	37831.81	41770.7	-0.12	0.26	0.22
	3939.64	37801.45	41741.09	-0.14	0.34	0.29
	3940.31	37774.45	41714.76	-0.16	0.41	0.36
	3942.34	37749.94	41692.28	-0.21	0.47	0.41
WEST	3934.42	37857.44	41791.86	-0.01	0.19	0.17
	3934.45	37833.25	41767.7	-0.01	0.25	0.23
	3934.48	37811.59	41746.07	-0.01	0.31	0.28
	3937.1	37793.19	41730.29	-0.08	0.36	0.32

BASE CASE RESULTS		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3934.12	37929.91	41864.03

OVERALL THE BEST RESULTS		
Orientation	Total imp(%)	Overlap Values(cm)
South	0.83	60
East	0.31	60
North	0.41	60
West	0.32	60

Appendix 3: The best results based on the factor

3.1. The best results of overhang shading devices

OVERHANG	Vertical offset	OVERALL THE BEST RESULTS		
	from top of window	Orientation	Total imp(%)	Vertical Values(cm)
	0,10,20,30 cm	South	6.23	0
		East	2.92	0
		North	0.53	0
		West	3.02	0

	Projection	OVERALL THE BEST RESULTS		
	0.5, 1, 1.5, 2 m	Orientation	Total imp(%)	Projection Values(m)
		South	6.23	1
		East	0.55	0.5
		North	4.04	2
		West	4.23	2

	Horizontal overlap	OVERALL THE BEST RESULTS		
	0,15,30,45 cm	Orientation	Total imp(%)	Overlap Values(cm)
		South	6.76	45
		East	3.09	45
		North	0.61	45
		West	3.18	45

3.2. The best results of louvre shading devices

LOUVRE	Vertical spacing	OVERALL THE BEST RESULTS		
	20,25,30,35 cm	Orientation	Total imp(%)	Vertical Values(cm)
		South	3.58	30
		East	2.62	30
		North	0.05	25
		West	2.76	30

	Distance from window	OVERALL THE BEST RESULTS		
		Orientation	Total imp(%)	Distance Values(cm)
	10,20,30,40 cm	South	3.95	10
		East	2.95	10
		North	0.07	10
		West	3	10

	Blade depth	OVERALL THE BEST RESULTS		
	15,20,25,30 cm	Orientation	Total imp(%)	Depth Values(cm)
		South	3.58	20
		East	3.18	30
		North	0.42	15
		West	3.31	30

	Angle	OVERALL THE BEST RESULTS		
	5,15,25,35 cm	Orientation	Total imp(%)	Angle Values(°)
		South	3.58	15
		East	2.74	25
		North	0.46	5
		West	2.86	25

3.3. The best results of sidefin shading devices

SIDEFIN	Horizontal offset from window	OVERALL THE BEST RESULTS		
		Orientation	Total imp(%)	Horizontal Values(cm)
	0,10,20,30 cm	South	0.75	0
		East	0.27	0
		North	0.36	0
		West	0.28	0
	Projection	OVERALL THE BEST RESULTS		
	30,40,50,60 cm	Orientation	Total imp(%)	Overlap Values(cm)
		South	0.94	30
		East	0.32	30
		North	0.41	30
		West	0.33	30
	Top and bottom overlap	OVERALL THE BEST RESULTS		
		Orientation	Total imp(%)	Projection Values(cm)
	0,10,20,30 cm	South	0.83	60
		East	0.31	60
		North	0.41	60
		West	0.32	60

Appendix 4: The best results based on the direction

4.1. The comparison of improvements on south and east direction

OVERHANG SOUTH		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
4029.93	35181.63	39211.56
		Total imp(%)
		6.34

OVERHANG EAST		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3947.42	37197.08	41144.5
		Total imp(%)
		1.72

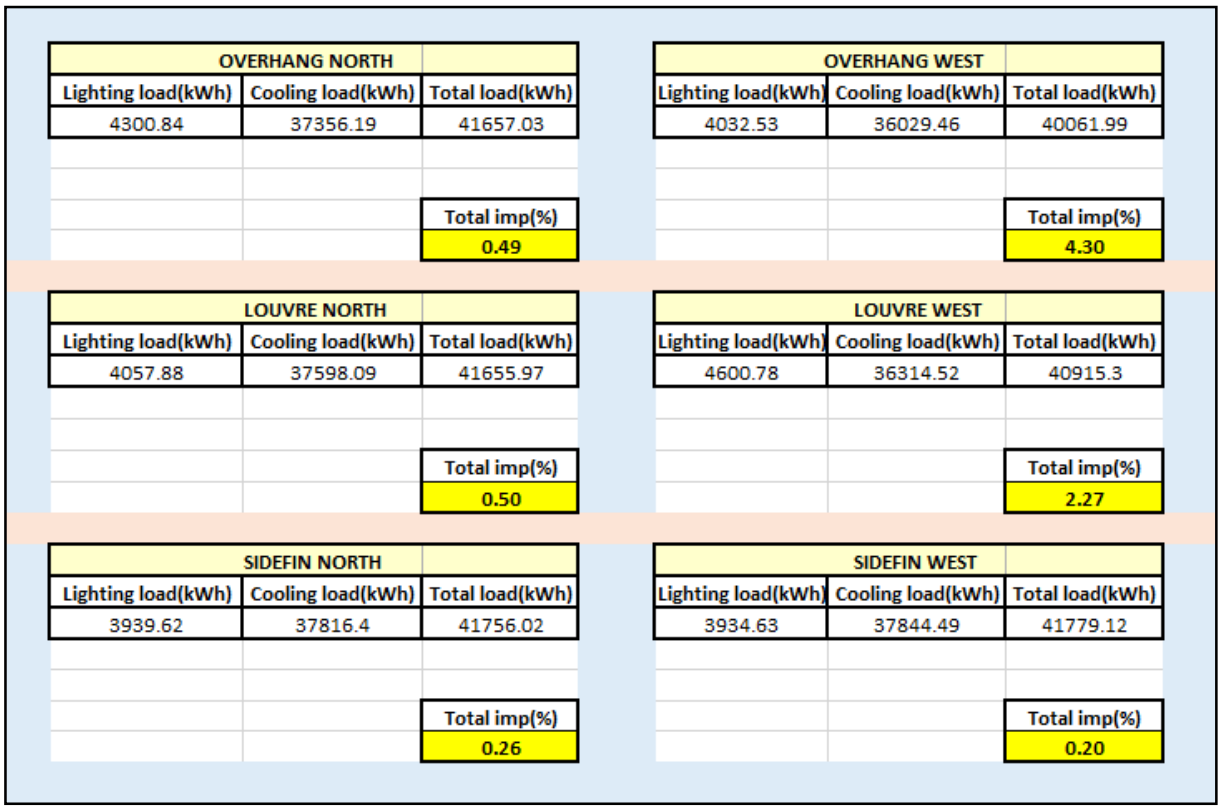
LOUVRE SOUTH		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
4537.79	35734.97	40272.76
		Total imp(%)
		3.80

LOUVRE EAST		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
4689.19	36449.57	41138.76
		Total imp(%)
		1.73

SIDEFIN SOUTH		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3938.23	37619.11	41557.34
		Total imp(%)
		0.73

SIDEFIN EAST		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3934.59	37847.35	41781.94
		Total imp(%)
		0.20

4.2. The comparison of improvements on north and west direction



OVERHANG NORTH		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
4300.84	37356.19	41657.03
		Total imp(%)
		0.49

OVERHANG WEST		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
4032.53	36029.46	40061.99
		Total imp(%)
		4.30

LOUVRE NORTH		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
4057.88	37598.09	41655.97
		Total imp(%)
		0.50

LOUVRE WEST		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
4600.78	36314.52	40915.3
		Total imp(%)
		2.27

SIDEFIN NORTH		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3939.62	37816.4	41756.02
		Total imp(%)
		0.26

SIDEFIN WEST		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3934.63	37844.49	41779.12
		Total imp(%)
		0.20

4.3. The comparison of improvements of overhang, louvre, sidefin and combinations

OVERHANG RESULTS		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
4566.38	32023.05	36589.43
		Total imp(%)
		12.60

LOUVRE RESULTS		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
7023.23	32775.41	39798.64
		Total imp(%)
		4.93

SIDEFIN RESULTS		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
3944.7	37337.75	41282.45
		Total imp(%)
		1.39

COMBINATION OVERALL		
Lighting load(kWh)	Cooling load(kWh)	Total load(kWh)
5392.03	31664.46	37056.49
		Total imp(%)
		11.48

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