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Optimizing energy consumption through canopy design and analysis of cooling load by simulation method (Case study: Warsaw factory in Borujerd)

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ABSTRACT

Energy saving and finding effective solutions have become important and notable topics in architecture in recent years. This issue is even more critical in countries with severe climatic conditions for most of the year. Therefore, in this study, an industrial building in the city of Borujerd was simulated using DesignBuilder software, and the cooling and heating loads were calculated.

The research question is: To what extent does the design of external shading devices in the rolling mill factory building in Borujerd affect the reduction of the cooling load on mechanical systems? The aim of this study is to examine the performance of the factory's external windows in terms of shading efficiency during the summer season in Borujerd's climate. Consequently, the software-based evaluation of energy loss before and after the installation of shading devices is conducted. The research approach is quantitative and uses a causal-experimental correlation method. Initially, the independent variables were manipulated, and then the effects on the dependent variables were observed. The parameters influencing the reduction of indoor temperature were analyzed by reviewing the temperature range chart and the need for a 45-degree shading device, using Climate Consultant software for the Borujerd climate. The cooling load in July decreased from -200 to 122 kWh, and accordingly, the amount of carbon dioxide produced was reduced from 78,788 to 52,637 kilograms.

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Introduction

Iran is among the countries that continue to be recognized as one of the highest consumers of non-renewable energies and fossil fuels, and it is a country with excessive energy consumption. On the other hand, according to the International Energy Agency's report, building energy consumption accounts for 40 percent of the total energy; meaning that buildings are the largest energy consumers globally (Zomorodian et al., 2019: 245-249). Given this, researchers are striving to find ways for building occupants to consume less energy while feeling comfortable (Bardbari et al., 2020: 1048). Approximately half of the world's energy consumption in buildings has made them the largest source of energy consumption globally and considered sources of carbon dioxide emissions, which play a significant role in environmental pollution (Rahmati Dehkordi & Jahangiri, 2022: 1). In this regard, various approaches such as green architecture and zero-energy architecture have been proposed, and efforts have focused on bringing the balance of energy production and consumption in buildings towards zero (Marszal et al., 2011). A closer look at these approaches, based on benefiting buildings from the advantages of nature and greenery, as well as local energy production in buildings and their independence from connection to the nationwide energy grid, can in many cases in different climates contradict the goals of sustainable development and lead to increased consumption of energy resources (Khatib & Akbari, 2024). The independence of buildings in energy production from central and nationwide systems can pave the way for greater energy consumption. Therefore, the principle remains on reducing energy consumption. One of the most important factors affecting the increase in energy consumption in buildings is openings and glass surfaces. Openings can lead to the loss of heating energy in cold regions or the cold season, and in warm regions and seasons, they can cause greater absorption of solar heat from the environment and increase the cooling load of mechanical installations. Based on this, proper shading design can effectively help illuminate the interior space with daylight, improve thermal comfort, control the increase in solar heat, and enhance the external view of the environment. Shading elements in different directions of building blocks located in shading devices have a significant impact on energy consumption values in all cases. Studies show that these elements have a positive effect on cooling loads and reduce annual cooling energy costs (Akalp & Özyılmaz, 2023: 121-122). However, it should be noted that the amount of energy received from outside or the energy loss inside the building depends on many factors, including the properties of insulation layers, building orientation, area of openings, material of openings, type of shading, climatic conditions, wind speed, building form, air infiltration coefficient, thermal conductivity or resistance of building materials, and technical specifications of dependent mechanical and electrical systems. Therefore, building simulation methods are one of the most efficient ways to accurately calculate the amount of reduction or increase in building thermal loads. This study attempts to calculate, using simulation, the amount of change in the cooling load imposed on the building installations of a Varshoosazi (Varnish Making) factory in Borujerd city after the design of shading devices.

Theoretical Framework of the Research

Energy consumption in the building sector has increased significantly over the past decade (Hamza et al., 2021: 116). Global greenhouse gas emissions are on a significant upward trend. In 2019, emissions from global buildings were 12 percent as carbon dioxide equivalent and 21 percent. Residential buildings consume 70 percent of the final energy needs of global buildings. Given current energy consumption and emission intensity, the construction industry's share of carbon emissions will reach 50 percent by 2050. Accordingly, the construction industry faces major challenges in energy conservation and greenhouse gas emission reduction (Yao et al., 2023: 1). Globally, the building industry consumes 40 percent of the energy, and its operational and consumption needs are expected to continue to increase in the coming years. In warm climates, the cooling demand for commercial buildings is a major concern for its operational needs and maintaining thermal comfort (Shaik et al., 2021: 1). Energy consumption in the building sector in Iran is higher than the global average; therefore, the country must play a role in mitigating the global problem of climate change and preserving fossil fuel resources; measures must be taken to reduce the heating and cooling energy used (Sadafi et al., 2021: 255). Heatwaves will be more frequent and intense in the future due to climate change, and as the weather warms over the years, the demand for cooling will increase. With the increase in the country's population due to the influx of immigrants, demand will also increase. This can put stress on the grid and lead to increased greenhouse gas emissions (Dana et al., 2021: 167-170). Energy efficiency means using less energy for heating, cooling, and lighting. It also means combining different methods to ensure energy conservation. Design Builder models can be easily used to display the complete technical specifications of a building and provide a suitable analysis of its environmental performance (Pawar and Kanade, 2018: 72). The construction of new buildings requires a revision towards reducing energy consumption by using renewable resources while ensuring the comfort and satisfaction of residents. In this regard, recent studies aim to focus on reducing building energy consumption (Azima and Seyis, 2023: 1). Poor building performance consumes a lot of electricity, which requires larger AC systems than necessary and longer operation, wasting electricity. Energy efficiency (EE) has been the easiest and most cost-effective issue to reduce energy consumption (Al-Anazi and Almasri, 2023: 1053). The gap between economic development and the environment must be bridged to achieve the main goal of maintaining a prosperous economy through reliance on clean energy sources. Climate change caused by greenhouse gas emissions in the atmosphere is one of the biggest challenges that arise (Ibrahim et al., 2021). In new buildings, the main measures taken to achieve suitable energy performance can be implemented during the design phase. For buildings that use these methods, the potential for energy savings is between 5 and 15 percent (Balbis-Morejón et al., 2021), both in energy consumption and carbon dioxide emissions. The report presented by the Intergovernmental Panel on Climate Change (IPCC) led to improved social knowledge and awareness about energy consumption and environmental consequences, and resulted in increased interest in obtaining a more appropriate insight into the characteristics of energy consumption in buildings (Esbati et al., 2020: 960). Heating, ventilation, and air conditioning (HVAC) equipment account for more than half of the total global annual

energy consumption. In 2019, space cooling accounted for 20 percent of all electricity consumed in buildings worldwide. Energy use for cooling systems is expected to increase from 32 percent of total building energy consumption in low-latitude countries (such as Africa, the Middle East, etc.) to 72 percent by 2100, mainly due to relatively warm outdoor temperatures, which is a product of climate change. Due to the hot, dry, and semi-arid climate and weather patterns, the Middle East is highly susceptible to the predicted effects of climate change (Albatayneh et al., 2022: 2). Optimally designed energy performance increases its energy performance, maximizes the movement of cooling air, and disregards the sun (increased heat) in the summer season because its performance depends on the climate and available resources (Shawkat et al., 2021: 60). The building sector, with more than 40 percent energy consumption, is the largest energy consumer in Iran. The average energy consumption of buildings in Iran is more than 2.5 times the global average. And more than 98.5 percent of the energy consumed in buildings in Iran is supplied through oil or gas. This makes the construction and housing sector one of the main sources of pollutants (about 26.4 percent of carbon dioxide emissions). Iran ranks seventh in the world in carbon dioxide emissions (Razazi, 2022: 75).

The basic goal of building retrofitting with energy saving is to improve the quality of the indoor thermal environment based on energy saving and economics. Decision-making on retrofitting costs considers the rate of energy saving and indoor thermal comfort as optimization indicators, and the relationships between these three indicators are mutually influenced and limited, which can be considered a multi-objective optimization problem (Cao et al., 2022: 2). A lot of thermal energy can be absorbed by surfaces. On a summer day, the roof can heat up to 70 degrees Celsius. Although roofing technologies are designed to withstand extreme heat, high temperatures can cause faster degradation of materials. The structure will experience an increase in internal temperature due to heat transfer from the roof (Albatayneh et al., 2022: 1-2). Ensuring greater efficiency of buildings is essential if energy use is to be sustainable in the future. For optimal thermal performance, there should be new and innovative designs for building construction. To achieve this goal, effective and accurate software programs are needed that can correctly predict the performance of buildings under different conditions. To increase the prediction of energy consumption in buildings and reduce their operating costs, it is essential to address all relevant physical, social, and environmental factors during construction (Albatayneh, 2021: 2). BIM tools can help designers explore different design alternatives in the early stages and effectively and quickly transfer design information to energy and simulation tools for validation and analysis. On the other hand, by using BIM tools, owners can better visualize the development of their construction projects in all different stages of their construction. The construction team uses BIM models to coordinate activities, extract material quantities, and identify potential conflicts between equipment (Danial et al., 2023). A suitable simulation tool is needed to simulate the performance of building systems effectively and correctly. DesignBuilder software was used in this study to evaluate the simulation of the building model. The calculation method of DesignBuilder depends on the power of the EnergyPlus simulation engine. DesignBuilder creates a virtual environment in which the building's HVAC and lighting systems are simulated. They are calculated without

compromising thermal comfort. DesignBuilder was used to predict the annual energy consumption of the building, paying attention to building design, building materials, optimized thermal comfort, lighting, weather data, and activity in the building construction case study (Danial et al., 2023). The size, aspect ratio, and position of windows were studied in several studies on heat loss from buildings through windows, showing that low aspect ratio windows with low emissivity can increase building efficiency. Modern cities use windows as the main architecture of high-rise buildings due to visual access to the surroundings and for the artistic look of buildings in the urban environment. However, more than 60 percent of energy loss from buildings is related to windows and window frames in hot and dry climates (Seadaghat, 2021: 2). Today, one of the simple and common methods that can be easily implemented in Iran is the use of shading devices. Adjusting optimal light and preventing direct sunlight and heat loss in winter are among the advantages of using shading devices. Shades may be installed internally or externally, and they may be fixed or movable, which again may be manual or automatic. Several research studies have evaluated the performance of shading devices. While external shades intercept solar radiation before it reaches inside the building, shades installed internally absorb solar radiation on the glazing system and then re-radiate it inside, which increases the cooling load (Razazi, 2022: 75). In order to protect against environmental degradation and the threatening scarcity of energy resources (especially today), the necessity of striving to achieve greenhouse gas emission neutrality from building resources by 2050 is of particular importance. To achieve this goal, all new buildings and 20 percent of the existing building stock must have net-zero emissions by 2030. In light of this, it is very important to know the impact of factors that determine the energy consumption of buildings, especially newly designed buildings (Jeziarski and Sadowska, 2022: 2). It is clear that energy consumption is one of the concerns of the world and the urban construction sector. One of the most important reasons for this consumption is a challenge that must be addressed, especially in developing countries. Building performances play a fundamental role in the impact and needs of building heating and cooling (Fernandes Maciel and Carvalho, 2021). The warmer climate in which a building is located affects the building's internal temperature. When the outside air temperature increases, the building will experience internal discomfort. High temperatures significantly affect electricity consumption in infrastructure; increased cumulative electricity demand and thermal gain are important parameters that affect energy consumption. Lower thermal gains will reduce cooling (Oluwatimilehin & Ayanlade, 2023). The use of shading systems, as a double protection against sunlight, can help balance the overall energy of these systems and be considered as a cost-effective and aesthetically acceptable means for integration with renewable systems in buildings. Proper shading design can effectively help illuminate the interior environment with daylight, improve thermal comfort, control the increase in solar heat, and enhance the external view of the environment. Shading elements in both directions of blocks located in shading devices have a negative impact on heating load values in all cases, and analyses have also shown that these elements increase annual heating costs, have a positive effect on cooling loads, and reduce annual cooling energy costs (Akalp & Özyılmaz, 2023: 121-122). Developments related to industrialization in the use of materials have increased the use of windows and walls in

buildings. This increase in the proportions of transparent surfaces in buildings has made window design a priority for addressing thermal comfort. For this reason, controlling heat loss or gains from window surfaces is an important design issue in providing thermal comfort. In order to minimize annual energy costs, it is possible to control direct or indirect light entering the building from window surfaces with appropriate shading elements. The main purpose of shading elements is to prevent sunlight from entering the transparent facades of the building in summer conditions and to stop the flow of unwanted energy inside the building.

Table 1. Summary of Climatic Data from Climate Consultant Software

WEATHER DATA SUMMARY		LOCATION: iran broujerd warshow, -											
		Latitude/Longitude: 33.826° North, 48.8° East, Time Zone from Greenwich 3											
		Data Source: MN7 999 WMO Station Number, Elevation 1521 m											
MONTHLY MEANS													
Global Horiz Radiation (Avg Hourly)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Wh/eq.m
Direct Normal Radiation (Avg Hourly)	335	381	427	483	524	586	559	560	550	448	367	323	Wh/eq.m
Diffuse Radiation (Avg Hourly)	584	522	470	484	517	647	590	636	735	633	620	610	Wh/eq.m
Global Horiz Radiation (Max Hourly)	84	111	147	160	163	123	142	125	92	97	91	76	Wh/eq.m
Direct Normal Radiation (Max Hourly)	681	833	935	1066	1081	1079	1077	1033	1030	909	716	689	Wh/eq.m
Diffuse Radiation (Max Hourly)	1002	1030	1000	1001	988	1000	992	978	1022	1022	1002	992	Wh/eq.m
Global Horiz Radiation (Avg Daily Total)	3359	4099	5058	6235	7235	8328	7825	7408	6738	4991	3763	3168	Wh/eq.m
Direct Normal Radiation (Avg Daily Total)	5848	5602	5562	6233	7146	9194	8265	8408	8977	7049	6335	5973	Wh/eq.m
Diffuse Radiation (Avg Daily Total)	851	1198	1748	2063	2253	1756	1886	1664	1127	1087	941	744	Wh/eq.m
Global Horiz Illumination (Avg Hourly)	35848	40754	45847	52292	56781	62952	60355	60450	58829	48229	39638	34771	lux
Direct Normal Illumination (Avg Hourly)	55274	48847	44448	46241	49727	62930	57161	61905	72457	61613	58923	57400	lux
Dry Bulb Temperature (Avg Monthly)	1	4	9	14	20	26	29	28	23	17	8	4	degrees C
Dew Point Temperature (Avg Monthly)	-4	-4	-2	1	3	2	4	3	0	0	0	-2	degrees C
Relative Humidity (Avg Monthly)	65	54	43	44	34	23	21	22	22	35	56	63	percent
Wind Direction (Monthly Mode)	70	210	210	210	200	240	210	260	240	200	110	70	degrees
Wind Speed (Avg Monthly)	0	1	1	1	1	1	1	1	1	1	0	0	m/s
Ground Temperature (Avg Monthly of 1 Depths)	12	9	8	9	12	15	19	21	22	21	19	15	degrees C

Then, based on the analysis of climatic data in the Climate Consultant software, the psychrometric chart, temperature range, and solar radiation chart for the city of Borujerd were extracted, which are presented below.

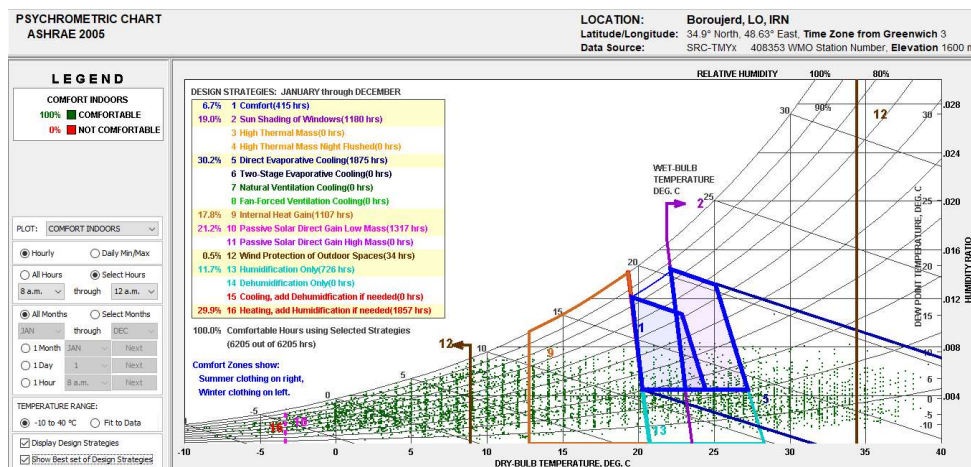


Figure 1. Psychrometric Chart and Thermal Range of Borujerd City

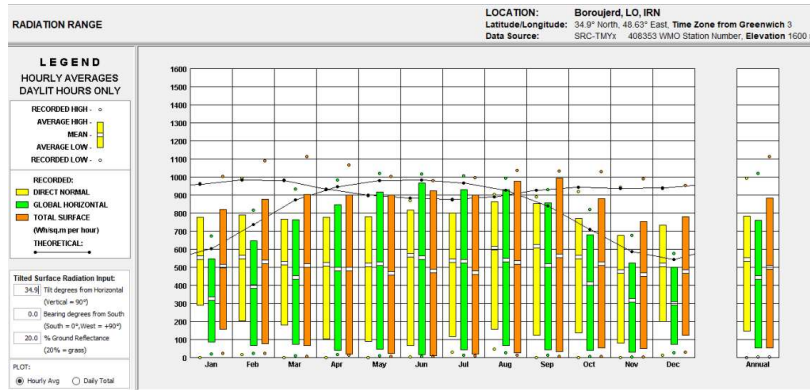


Figure 2. Air temperature radiation in the city of Boroujerd during different months

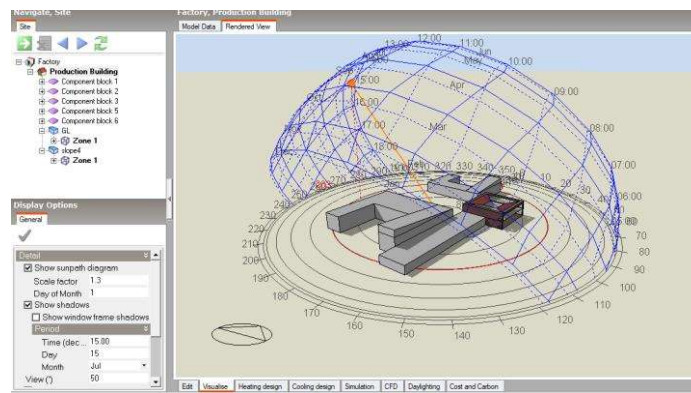


Figure 3. Simulated model of the rolling mill factory building in Boroujerd city using DesignBuilder software.

Analysis and Evaluation of the Shading Device

According to the "Sun Needed" chart in the Climate Consultant software, sunlight is required during the winter season.

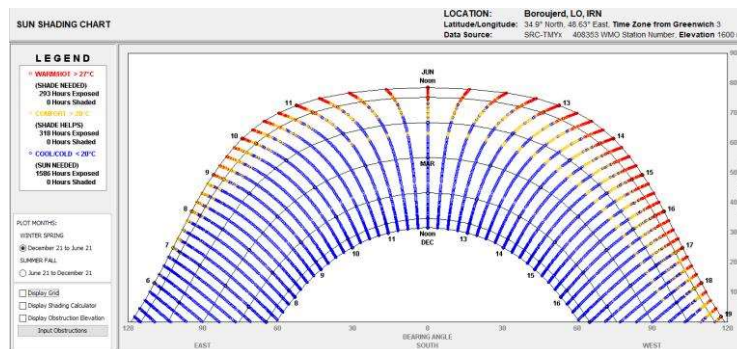


Figure 4. Sun Shading Diagram (Sun Needed and Shade Needed)

According to the "Shade Needed" graph, shading devices are required during the summer season. In the diagram below, the horizontal shading angle was determined to be approximately 45 degrees using Climate Consultant software.

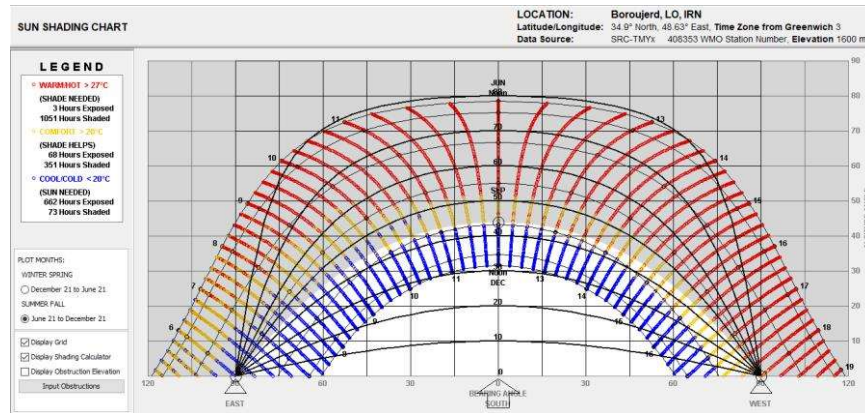


Figure 5. Determination of the Horizontal Shading Angle (Shade Needed) Using Climate Consultant Software, Approximately 45 Degrees for the Rolling Mill Factory Building in Borujerd

Table 2. Materials Used in the Modeled Production Building of the Borujerd Rolling Mill Factory in DesignBuilder Software

Construction						
External wall	Layers	Thickness	Thermal Resistance (m ² .K/W)	Conductivity (W/ m.K)	Specific Heat(J/Kg.K)	Density (KJ/m ³)
	1. Brick	0.1	-	1.33	900	2000
	2. Air space	0.0792	0.16	-	-	-
	3. Heavy concrete	0.15	-	0.67	800	900
	4. Finish	0.01	-	0.42	1100	1250
	5. Foam-polyurethane	0.15	-	0.280	1470	30
Internal wall	1. Gypsum Plasterboard	0.025	-	0.25	1000	900
	2. Air gap	0.10	0.15	-	-	-
	3. Gypsum Plasterboard	0.025	-	0.25	1000	900
Flat roof	1. Plaster	0.05	-	0.56	1000	500
	2. Light concrete	0.12	-	0.67	600	800
	3. Finish	0.01	-	0.42	1100	1250
Pitched roof	1. Clay tile	0.025	-	1	800	2000
	2. MW Stone wool (rolls)	0.1819	-	0.04	840	30
	3. Roofing felt	0.005	-	0.19	837	960
Internal roof	1. گرانیت	0.02	0.007	-	-	-
	2. ملاط ماسه سیمان	0.05	0.05	-	-	-
	3. Light concrete	0.05	0.15	-	-	-
	4. تیرچه بلوک	0.25	0.15	-	-	-
	5. Finish	0.01	0.16	-	-	-

In the chart of Figure 6 below, the thermal comfort range for the studied climate has been extracted from the Climate Consultant software for the months of the year. Accordingly, the summer months in Borujerd are June, July, and August.

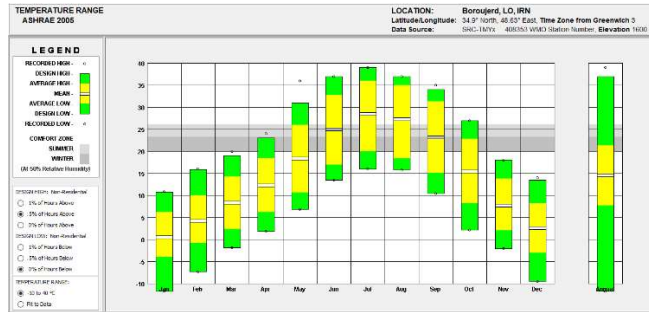


Figure 6. Thermal Comfort Range for the Target Climate from Climate Consultant Software

Following this, the analysis of the solar radiation angle on the roof on July 15, based on the temperature range, is presented.

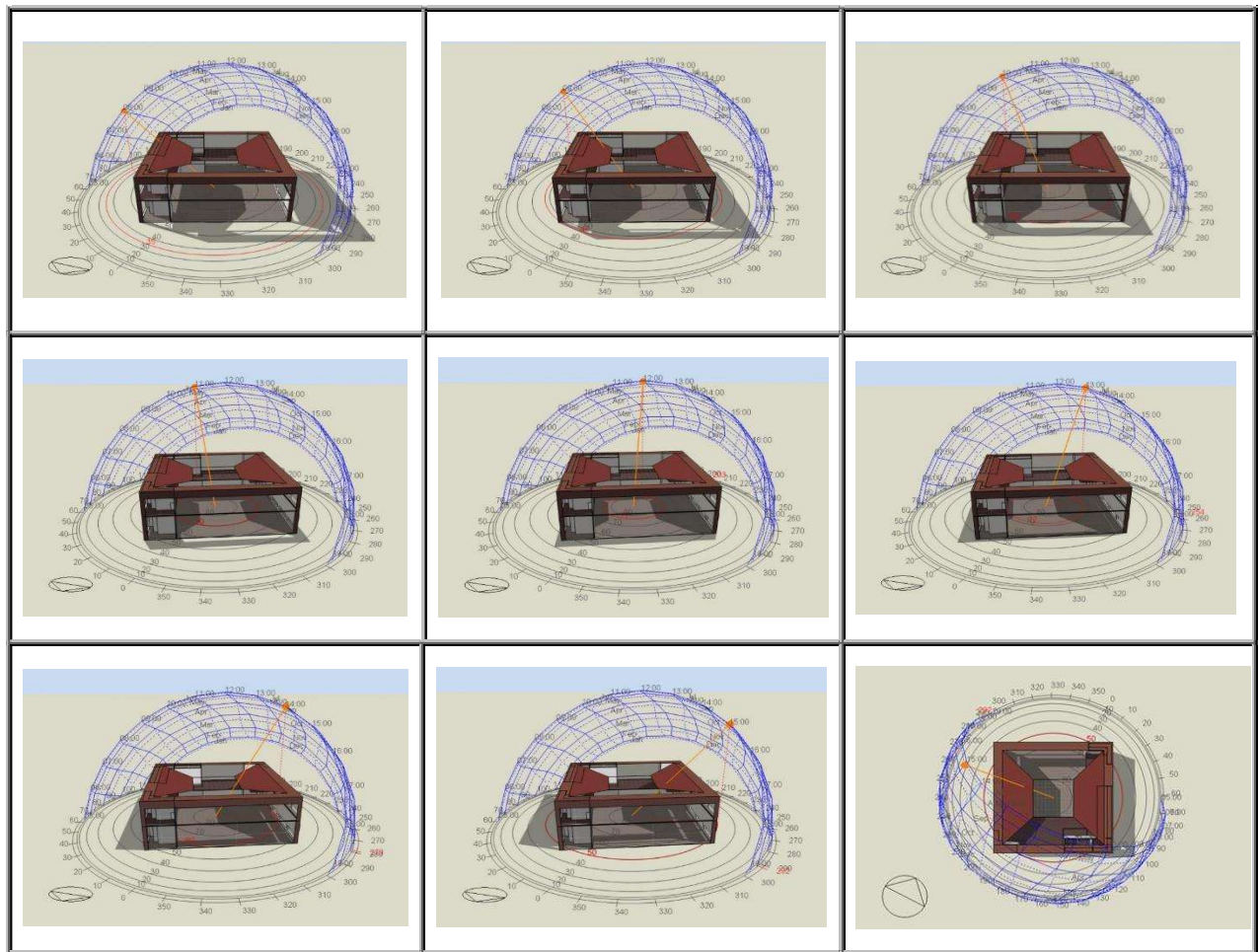


Figure 7. Examination of the Sun's Angle of Incidence on the Roof on July 15 Based on the Temperature Range Simulated in DesignBuilder Software

After placing 50% of the window openings on the roof facing upward in the square-shaped roof window and analyzing the cooling load, the results of the cooling load analysis before and after installing the shading device were reviewed. The results are as follows:

Results of the Analysis Without Shading Device

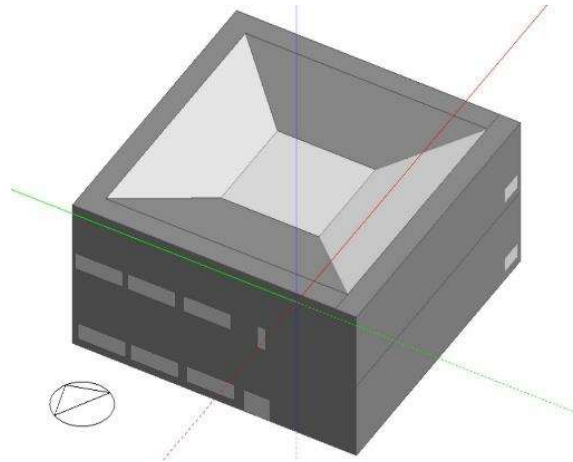


Figure 8. Simulated model of the industrial building without external shading in DesignBuilder software.

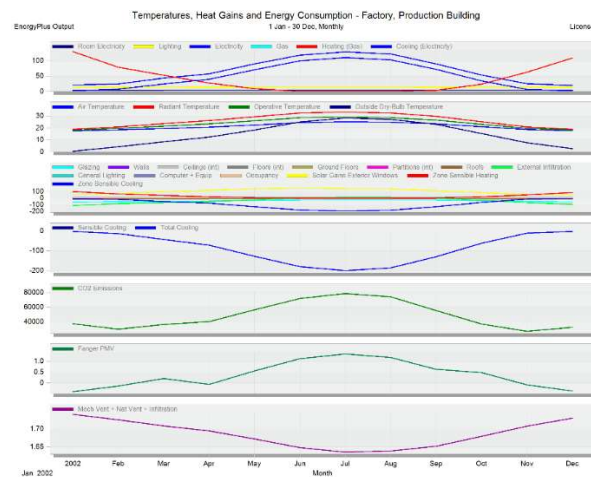


Figure 9. Temperature, Heat, Energy, and Cooling Load in DesignBuilder Software

Table 3. Temperature, Heat, Energy, and Cooling Load in DesignBuilder Software

Temperatures, Heat Gains and Energy Consumption - Factory, Production Building											
1 Jan - 30 Dec, Monthly											
EnergyPlus Output	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Dec
Room Electricity (MWh)	4.32	3.84	4.32	4.00	4.32	4.16	4.16	4.32	4.00	4.32	4.16
Lighting (MWh)	15.01	13.34	15.01	13.89	15.01	14.45	14.45	15.01	13.89	15.01	14.45
Electricity (MWh)	21.17	24.58	43.73	57.84	59.45	118.57	130.01	122.52	90.39	54.08	24.94
Gas (MWh)	130.46	79.70	52.72	27.46	9.29	0.75	0.02	0.04	3.41	23.63	63.13
Heating (Gas) (MWh)	130.46	79.70	52.72	27.46	9.29	0.75	0.02	0.04	3.41	23.63	63.13
Cooling (Electricity) (MWh)	1.94	7.41	24.41	59.94	71.13	99.95	111.40	103.20	72.50	34.75	6.33
Air Temperature (°C)	17.56	18.44	19.56	20.75	22.50	24.43	25.92	24.90	23.49	21.13	18.76
Radiant Temperature (°C)	18.83	20.93	23.62	26.17	29.50	32.68	33.44	32.58	29.82	25.23	20.81
Operative Temperature (°C)	18.19	19.68	21.59	23.46	26.00	28.56	29.38	28.74	26.66	23.18	19.78
Outside Dry-Bulb Temperature (°C)	0.59	4.23	8.42	12.31	16.40	20.00	23.53	27.32	23.18	15.40	7.70
Glazing (MWh)	-82.74	-51.77	-52.97	-44.65	-37.90	-28.92	-23.07	-25.57	-31.15	-41.04	-47.99
Walls (MWh)	-1.98	-1.63	-1.63	-1.41	-1.05	-0.26	0.17	0.20	0.11	-0.73	-1.77
Ceilings (int) (MWh)	0.31	0.94	1.59	2.16	2.80	3.38	3.19	3.00	2.17	0.93	0.10
Floors (int) (MWh)	-0.30	-0.95	-1.58	-2.20	-2.82	-3.41	-3.18	-2.96	-2.11	-0.89	-0.08
Ground Floors (MWh)	-6.56	-7.38	-8.24	-7.85	-6.13	-4.42	-2.86	-1.83	-1.48	-1.84	-3.03
Partitions (int) (MWh)	0.02	-0.02	0.01	-0.06	-0.04	-0.05	0.00	0.02	0.07	0.05	0.01
Roofs (MWh)	-14.49	-11.17	-11.06	-8.28	-5.96	-2.19	-0.90	-1.84	-3.60	-7.68	-13.47
External Infiltration (MWh)	-110.88	-82.59	-70.17	-50.40	-24.39	4.11	19.97	15.37	-1.01	-34.68	-67.64
General Lighting (MWh)	15.01	13.34	15.01	13.89	15.01	14.45	14.45	15.01	13.89	15.01	14.45
Computer + Equip (MWh)	4.32	3.84	4.32	4.00	4.32	4.16	4.16	4.32	4.00	4.32	4.16
Occupancy (MWh)	7.90	6.60	6.61	5.73	5.51	4.77	4.54	4.85	4.84	6.12	7.26
Solar Gains Exterior Windows (MWh)	57.75	67.44	100.09	116.00	140.17	150.38	148.21	138.12	112.51	84.65	55.51
Zone Sensible Heating (MWh)	99.48	61.18	41.10	21.46	7.38	0.62	0.06	2.75	18.51	49.03	84.30
Zone Sensible Cooling (MWh)	-6.76	-18.11	-49.86	-76.93	-129.74	-177.35	-195.12	-181.11	-128.74	-65.17	-15.90
Sensible Cooling (MWh)	-3.32	-13.33	-43.93	-71.90	-127.95	-179.91	-200.49	-185.73	-130.50	-62.56	-11.40
Total Cooling (MWh)	-3.32	-13.33	-43.93	-71.90	-128.03	-179.93	-200.52	-185.75	-130.50	-62.56	-11.40
CO2 Emissions (kg)	37297.17	29847.12	36389.72	40200.79	56556.93	71993.71	78788.57	74255.76	55417.88	37204.10	26955.08
Fanger PMV (i)	-0.41	-0.14	0.21	-0.06	0.55	1.12	1.34	1.17	0.63	0.48	-0.09
Mech Vent + Nat Vent + Infiltration (ach)	1.74	1.73	1.71	1.69	1.67	1.65	1.64	1.64	1.65	1.68	1.71

Results of the analysis including east-west shading devices

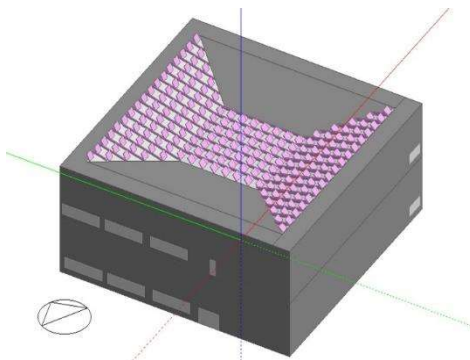


Figure 10. Simulated model of the industrial building without external shading in DesignBuilder software.

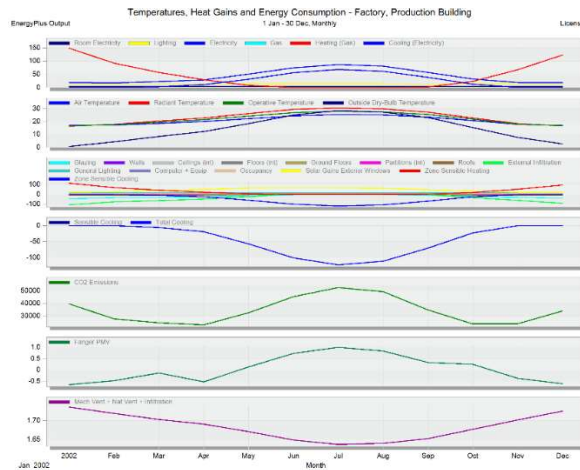


Figure 11. Temperature, Heat, Energy, and Cooling Load in DesignBuilder Software

Table 4. Temperature, Heat, Energy, and Cooling Load in DesignBuilder Software

Temperatures, Heat Gains and Energy Consumption - Factory, Production Building												
EnergyPlus Output	1 Jan - 30 Dec, Monthly											
	Month											
Room Electricity (MWh)	4.32	3.84	4.32	4.00	4.32	4.16	4.16	4.32	4.00	4.32	4.16	4.00
Lighting (MWh)	15.01	13.34	15.01	13.89	15.01	14.45	14.45	15.01	13.89	15.01	14.45	13.89
Electricity (MWh)	19.33	17.22	22.83	28.68	51.05	74.81	86.86	81.12	56.79	31.88	18.63	17.89
Gas (MWh)	149.05	92.00	57.20	29.37	8.62	0.30	0.00	0.00	1.96	23.21	67.36	123.60
Heating (Gas) (MWh)	149.05	92.00	57.20	29.37	8.62	0.30	0.00	0.00	1.96	23.21	67.36	123.60
Cooling (Electricity) (MWh)	0.00	0.04	3.50	10.79	31.73	56.20	68.25	61.80	38.90	12.55	0.02	0.00
Air Temperature (°C)	16.87	17.38	18.65	20.11	22.27	24.44	25.45	25.00	23.50	20.77	17.77	16.96
Radiant Temperature (°C)	16.38	17.83	20.33	22.77	25.23	29.50	30.57	29.78	27.27	22.82	18.35	16.62
Operative Temperature (°C)	16.63	17.61	19.49	21.44	24.25	26.97	28.01	27.39	25.39	21.79	18.06	16.79
Outside Dry-Bulb Temperature (°C)	0.59	4.23	8.42	12.31	18.40	25.00	28.53	27.32	23.18	15.40	7.70	2.67
Glazing (MWh)	-44.11	-33.52	-31.84	-24.25	-15.85	-5.65	0.01	-2.59	-9.04	-20.98	-29.40	-39.37
Walls (MWh)	-1.68	-1.29	-1.24	-1.03	-0.69	0.06	0.47	0.48	0.36	-0.45	-1.06	-1.51
Ceilings (int) (MWh)	-1.06	-0.48	-0.15	0.16	0.44	0.84	0.73	0.59	0.18	-0.62	-0.94	-1.11
Floors (int) (MWh)	1.07	0.47	0.16	-0.22	-0.46	-0.67	-0.73	-0.57	-0.12	0.65	0.95	1.14
Ground Floors (MWh)	-5.65	-6.20	-7.04	-6.69	-5.04	-3.42	-1.93	-0.95	-0.61	-0.79	-2.06	-3.58
Partitions (int) (MWh)	0.02	-0.02	0.01	-0.07	-0.05	-0.05	0.00	0.02	0.08	0.05	0.01	0.05
Roofs (MWh)	-12.89	-9.28	-8.70	-5.92	-3.51	0.05	1.20	0.14	-1.91	-5.98	-9.10	-12.00
External Infiltration (MWh)	-105.77	-76.09	-64.29	-46.49	-23.11	3.75	18.80	14.31	-1.34	-32.50	-61.31	-89.08
General Lighting (MWh)	15.01	13.34	15.01	13.89	15.01	14.45	14.45	15.01	13.89	15.01	14.45	13.89
Computer + Equip (MWh)	4.32	3.84	4.32	4.00	4.32	4.16	4.16	4.32	4.00	4.32	4.16	4.00
Occupancy (MWh)	8.20	7.04	7.23	5.99	5.59	4.77	4.50	4.83	4.86	6.29	7.45	7.55
Solar Gains Exterior Windows (MWh)	22.42	26.68	42.69	50.84	63.32	68.57	65.94	60.95	47.50	34.16	21.70	20.02
Zone Sensible Heating (MWh)	112.93	69.49	43.85	22.52	6.73	0.23	0.00	0.01	1.54	17.91	51.46	93.92
Zone Sensible Cooling (MWh)	-0.49	-1.82	-10.25	-23.25	-58.48	-98.56	-117.58	-106.67	-68.19	-24.55	-2.45	-0.64
Sensible Cooling (MWh)	0.00	-0.07	-6.30	-19.42	-57.94	-101.15	-122.83	-111.22	-70.02	-22.60	-0.04	-0.00
Total Cooling (MWh)	0.00	-0.07	-6.30	-19.42	-57.11	-101.16	-122.85	-111.24	-70.02	-22.60	-0.04	-0.00
CO2 Emissions (kg)	39667.49	27691.19	24562.01	22890.04	32553.53	45390.99	52637.00	49161.57	34784.46	23672.78	23924.59	34025.46
Fanger PMV (I)	-0.65	-0.48	-0.14	-0.53	0.14	0.73	1.01	0.84	0.33	0.25	-0.37	-0.61
Mech Vent + Nat Vent + Infiltration (ach)	1.74	1.72	1.70	1.69	1.67	1.65	1.64	1.64	1.65	1.68	1.70	1.73

Conclusion

Based on the analysis of the sun shading chart in Climate Consultant software for the climate of Borujerd, by inputting the relevant climatic data of Borujerd into the software and considering the temperature range and thermal comfort zone during the summer month of July and the summer season for Borujerd's climate, the need for shading (shade needed) was evident. Reviewing the sun shading chart in Climate Consultant indicated that a horizontal shading angle of approximately 45 degrees was required.

Subsequently, by modeling the project building in DesignBuilder software and applying shading devices with a 45-degree angle on the roof, the cooling load results were calculated. According to the results, before and after installing the shading devices for Borujerd's climate, the cooling load in July decreased from -200 to 122 kWh. Consequently, the carbon dioxide emissions were reduced from 78,788 to 52,637 kilograms.

Therefore, it can be concluded how significantly the design of shading devices can impact climate-responsive architecture and the reduction of non-renewable energy consumption.

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