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CASE STUDY RESEARCH PAPER

Evaluating the energy consumption of office buildings according to the materials and dimensions of the opening in the simulation chamber (Case Study: Tehran city)

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ABSTRACT

In Iran, due to the low price of energy carriers, the amount of energy consumption in the country is high and it is considered one of the countries with very high energy consumption. The aim of this research is to investigate the amount of energy consumption in its optimization approach in a simulation room in Tehran, which is done by focusing on the type of openings and its dimensions and evaluated by Design builder software. The first stage of the simulation of the heating and cooling load of the simulated room was with 27 samples of opening combinations with glass, gas and different frames. The second stage is the evaluation of 4 opening modes with the size ratio of 1 to 1, 1 to 2, 2 to 1 and 2 to 2, which determines the best aspect ratio for the opening. Findings shows shows the comparison of the monthly average cooling load in the dimensions selected for four types of windows, shows that the highest cooling load is observed in type D and size 2.3, which is the largest opening size in the four options selected for evaluation, and naturally It leads to more cooling load. Types A and B, which indicate the dimensions of 1.5 x 2 and 1 x 2, show almost the same values in comparison of the average cooling load. Among these, the best result belongs to type C with dimensions of 2 x 2, which has the lowest amount of cooling load.

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INTRODUCTION

After the industrial revolution, the world strangely faced the phenomenon of increasing greenhouse gases. These gases are caused by uncontrolled use of fossil fuels. According to the studies and investigations, the amount of carbon dioxide emitted in 2020 has increased by 31% compared to the era before the industrial revolution and has reached a figure equal to 790 tons (Haug, 2023). With the increase in per capita energy consumption, the population of countries, in order to maintain their survival and continue to live, forcefully consume all their fossil fuel resources; The increase in the consumption of these sources of energy will increase the emission of greenhouse gases and will cause fatal climate changes. Therefore, controlling the population increase in an environment will have a direct impact on the conservation of energy resources. By having sufficient control over this issue, environmental threats are also minimized (Liu, 2023). Cities are a dynamic and vital part of global culture and the main engines of social, economic and technical development; But to meet their population with thousands of service requests, they need a lot of energy. Currently, most of this energy is produced based on fossil fuels. Like the increase in urban population and economic activities and wealth, the use of energy in the city is also increasing (Dong et al., 2021).

- The scale and pattern of urban energy consumption are such that it has important consequences for both energy supply and global emission of greenhouse gases (Arenas and Shafique, 2023). The global energy perspective states the importance of paying attention to cities in the energy debate due to the following reasons of the International Energy Agency in the eighth chapter of the report: Currently, cities use more than two-thirds of the world's energy and are responsible for the emission of more than 70 % of CO_2 gas in the world.
- Simultaneously with the growth of urbanization, urban energy consumption is increasing significantly; According to the reference scenario, by 2030, energy consumption in cities will increase to 73% of the total global energy consumption and CO_2 emissions to 76%. Considering the scale of energy consumption and CO_2 emissions in the city, this growth can be limited if cities and urban authorities act to mitigate climate change. (Farghali et al., 2023) Also, urban density, buildings and spatial organization are critical elements that affect energy consumption, especially in buildings and transportation system. Urbanization and increase in prosperity has happened with the expansion of cities and increased demand for land; In fact, although the urban population has doubled, urban land has tripled.

In the past few decades, the rapid growth of urbanization and the expansion of industrial activities have reduced urban infrastructure and increased environmental waste, and cities have become synonymous with growth and are increasingly exposed to unfortunate crises, especially in developing countries (Isharque et al., 2021). Currently, cities are the main types of human-made environments, the most concentrated development points, the densest areas of human use of land, and the most compact spaces for the manifestation of human needs. Poverty, environmental destruction, lack of urban services, decline of existing infrastructure, lack of access to land and proper shelter are among the crises related to this issue (Rehman et al., 2021). At the same time, urban centers are considered the most critical places on the planet in terms of sustainable development concepts (Mokhtara et al., 2021). The intensity of energy consumption in Iran compared to other countries is also very high compared to the world average. Also, the amount of energy consumption in Iran is increasing at a high rate every year; In such a way that if the energy consumption production process continues in the current form, it will turn Iran into an energy importer in the near future (Abdalla et al., 2021). Despite having 1% of the world's population, Iran consumes 9% of petroleum products. The growth of energy consumption in our country, in a period of 16 years, has been estimated at an average of 5.8% per year.

According to the conducted studies, the average growth of world energy consumption in 10-year cycles from 1986 to 1996 was equal to 15%; In addition, energy consumption in Iran has grown by 81% in a period of 19 years. In the country, the highest amount of energy consumption is in the domestic, commercial, transportation, industry and agriculture sectors, respectively. According to these statistics, energy consumption in the domestic and commercial sectors was 44.30%, transportation 29.73%, industry 22% and agriculture 3.97%. In other words, the largest share of energy consumption belongs to the domestic and commercial sector, while in developed countries this sector occupies a much smaller share than the industry sector. As mentioned, the housing sector is one of the major sectors in energy consumption and includes about 40% of the waste and energy consumption in buildings. Also, this sector accounts for about 29.4% of carbon dioxide emissions in Iran (Akarsu and Genc, 2022). Therefore, reducing these numbers can have a significant impact on the country's total energy consumption. In addition to this, the energy saving potential in the building and housing sector is greater than in other sectors, reducing energy consumption in this sector is easy and accessible with less investment than other sectors, energy is one of the most important resources and the main basic force of life. It is considered human (Dar et al., 2022). In the last century, after the industrial revolution, the abundant exploitation of fossil energy sources caused more and more dependent of different sectors on this type of energy. The depletion of non-renewable energy due to the strong dependence of the industry and the domestic sector of countries on it caused wide economic problems and consequences. It will be worldwide. Therefore, countries sought to find a solution to reduce the use of non-renewable energy and replace this energy with unlimited sources of clean energy. In Iran, due to the dependence of the economy on the export of gas and oil, the increase in domestic consumption causes a decrease in the export of these products and affects the country's economy. And the application of measures to save energy consumption can cause a huge leap in the country's economy (Hong et al., 2021). In addition to this depletion or reduction of oil and gas reserves, irreparable economic crises will follow for the country. In Iran, due to the low price of energy carriers, the amount of energy consumption in the country is high; In fact, Iran is not in a favorable situation in terms of energy consumption for the production of goods and services, and it is considered one of the countries with very high energy consumption. In 2019, on average, around 122.6 tons of crude oil equivalent of energy were consumed to produce one million dollars of added value. While this figure in Iran is nearly 2 times the global average. Currently, by implementing topic 19, it is possible to save up to 50% in energy consumption, which includes a figure equivalent to 6 billion dollars per year.

MATERIALS AND METHODS

Simulation of energy consumption in buildings

In the field of sustainable design, there are software for energy calculations, by which the analysis of energy-related issues in the building sector is performed. Since the 1960s, when the first energy simulation softwares were produced, the power and efficiency of these softwares have increased in performing complex calculations. In general, energy and building software can be classified into four areas of thermal analysis, fluids, lighting and acoustics. Also, energy simulation software is a tool that has been created to predict the behavior of building energy consumption according to the way of providing thermal comfort for one year and with different outputs. Another function of energy simulation software can be considered as the ability to compare the ability of different active and passive strategies to reduce energy consumption and create thermal comfort with each other and achieve more effective solutions. Some energy simulation software can be the basis of design decisions due to different capabilities. By using this type of software, all the factors affecting the energy consumption of the building are simulated simultaneously and integrated, and their mutual effects on each other are taken into account to determine the amount of consumption and comfort conditions created in the simulation. Design Builder and Energy Plus can be mentioned among these software. It should be noted that the evaluation engine of Design Builder software as well as many other software is Energy Plus.

Energy simulation input data

Energy simulation softwares usually perform hourly calculations to determine the heating conditions of the interior spaces of the building, and therefore require the use of hourly data of climatic elements, including sunlight, temperature, humidity, etc., at least for a period of one year. In some simulations, based on the case studies, the averages of ten years or more are also needed. Although the information required to perform the simulation and the outputs from the energy simulation are different in various software, therefore the following can be considered as the inputs and outputs of these softwares, which can often be extracted from the existing standards, including the Ashri standard. Are Climate data Climate data is the basis of energy simulation. These data are available in the form of files with the extension epw, wea, TMY. These data are not prepared for all Iranian cities. The most common ones are epw files, which are accepted as input files by Energy Plus software and other software that uses its simulation engine. The type of structure includes the type of structure, the characteristics of the materials used, and the characteristics of the different layers of the building walls. Energy simulation software has the ability to determine the amount of internal load of buildings caused by the presence of occupants, using an hour-by-hour schedule. Therefore, the type of coverage and the amount of activity of people in these times is also among the information that the software receives for simulation. The amount of use of other equipment, such as office and lighting, other case information, this information is different depending on the type of problem, and for example, it can be the schedule of opening and closing openings or valves. The geometry of the building, the shape, size and type of contiguity of different thermal zones, openings, shade sizes, in line with the location of the building in relation to Khor Shed and other information related to the volume of the building are determined by introducing the geometry of the building for the software. Entering information related to mechanical facilities is one of the most difficult steps of working with energy simulation software for architects. Due to the direct influence of these equipments on the provision of thermal comfort and the amount of energy consumption in the building, in some energy simulation software it is necessary to define the specifications of these equipments for simulation. In other types of software, one of the default systems can be determined in the software. Due to the high investment cost and the long investment return phase of energy consumption optimization projects of buildings, it is necessary to carefully evaluate energy consumption reduction solutions before implementing. Due to the wide range of parameters involved in energy consumption, it is practically not possible to make decisions about strategies and design components without using simulation tools (Guo et al., 2021).

Design builder software

There are various formulas and methods to calculate the thermal load of the building. One of the best methods is to use energy modeling software. Because software for simulating the complex energy consumption of the building with the external environment of the building are useful tools that have the ability to consider all the complex interactions of the building with the external environment and internal systems, and therefore can be one of the most useful calculation techniques in relation to be considered by saving energy in the building sector. One of these softwares is the Design Builder software, which is a very comprehensive and advanced software of the Energy Plus 2 softwares and has the ability to provide the desired climate results such as heating, cooling, lighting by providing hourly weather data for each climate. Estimate natural and... The way to work with this software is that at first, the desired building is drawn in its environment with the help of drawing commands. Then, by applying the materials of the walls, openings, determining the facility system, determining the use of the building, etc., it calculates the thermal load of the complex. Determining the usage is important because buildings have different usage hours based on usage. By default, the working hours of the office building are from 8 am to 5 pm. Therefore, there is no need to operate the installation system after this hour. Also, the amount of lighting required depends on the type of use and the hours of use of the building. This software has the ability to better calculate the amount of energy consumption by giving a specific schedule for turning on and off facilities and lighting.

METHODOLOGY

The simulation in this research was done using Design builder software, which is a software for building energy analysis and measures the impact of environmental factors on the building. The capabilities of this software include calculating the total energy consumption of the building, calculating the heating and cooling load of the building, imaging solar radiation on windows and other surfaces, calculating daylight factors, and displaying the position of the sun and the path of the sun relative to the model every day and hour. This software can calculate the amount of energy consumed per hour, day, month and year based on weather information and help the design team to make design decisions based on real information. The validity of Design builder software has been proven in many previous researches. By referring to the main page of the website of this software, it can be seen that the results of the simulations by entering the characteristics and weather data of different regions are completely valid and recognized in the decision-making authorities of England) SBEM Approval). By using Design builder simulation software, the thermal behavior of the building is changed according to the main variables that are investigated, the type and dimensions of the openings, and thermal simulation has been done for each of these variables. Therefore, it is possible to calculate what changes will occur in the cooling and heating load of the building. Finally, data analysis is done according to the graphs extracted from this software. The method of this research is done in three stages. The first stage of the simulation of the heating and cooling load of the simulated room was with 27 samples of opening combinations with glass, gas and different frames, and the results of this evaluation section determine the best material combination for the opening. The second stage is the evaluation of 4 opening modes with the size ratio of 1 to 1, 1 to 2, 2 to 1 and 2 to 2, which determines the best aspect ratio for the opening. The final stage is modeling the villa of the final design and simulating its heating and cooling load using windows with optimal materials and dimensions to optimize energy consumption in the entire case. The research method is such that, at first, information on the type and dimensions of the openings is determined. Then, the proposed scenarios are modeled in the software, and by analyzing the data, the software obtains the energy consumption of the building in the form of total energy required for cooling the building (TOTAL COOLING) and energy required for heating the building (ZOON HEATING), etc.

Evaluating the energy consumption of openings

Openings are the main communication ways inside and outside the building and are considered one of the most important ways of transferring heat between the inside and outside of the building. The correct selection of each window has a special contribution to energy consumption. One of the ways to improve the efficiency of windows is double glazing. The double-glazed window has 2 panes in which there is a fully sealed space. This distance is usually between 6 and 20 mm. The middle space of these glasses is filled with argon, krypton or air gases. Also, double-glazed windows, although it reduces heat loss, does not prevent sunlight from entering. In this part of the research, the solutions for improving the thermal behavior of openings have been investigated. In the first part, the windows have been modeled and simulated in 27 different states in terms of their components and materials, i.e. The type of glass, the gas inside the glass layers, and the type of frames. Based on the results of the simulation, the best type of glass, the better gas used, and the best frame material have been determined. It should be noted that the area of the windows is taken as 30% of the area in the software. Table 1 shows 27 simulation models of 3 types of double-glazed glass with different thicknesses. In addition, apart from the thickness of the glass, variables including the type of frame (aluminum with thermal insulation, aluminum without thermal insulation and upvc) and the type of gas (krypton, argon and the combination of argon and air gases) are applied in the table and in the form of a sample model of a room in the building. The case was designed, modeled and then energy simulated using Design Builder software. The results of this simulation are shown in graphs 1 to 3.

Table 1: Different types of windows

Window type	Glass material	Type of gas used	The type of frame used
W01	Dbi clr3mm/6mm	Arg/air95/5	upvc
W02	Dbi clr3mm/6mm	Arg/air95/5	Frame Alu(insulation)
W03	Dbi clr3mm/6mm	Arg/air95/5	Frame Alu(no insulation)
W04	Dbi clr3mm/6mm	Kryp	upvc
W05	Dbi clr3mm/6mm	Kryp	Frame Alu(insulation)
W06	Dbi clr3mm/6mm	Kryp	Frame Alu(no insulation)
W07	Dbi clr3mm/6mm	Arg	upvc
W08	Dbi clr3mm/6mm	Arg	Frame Alu(insulation)
W09	Dbi clr3mm/6mm	Arg	Frame Alu(no insulation)
W10	Dbi clr3mm/13mm	Arg/air95/5	upvc
W11	Dbi clr3mm/13mm	Arg/air95/5	Frame Alu(insulation)
W12	Dbi clr3mm/13mm	Arg/air95/5	Frame Alu(no insulation)
W13	Dbi clr3mm/13mm	Kryp	upvc
W14	Dbi clr3mm/13mm	Kryp	Frame Alu(insulation)
W15	Dbi clr3mm/13mm	Kryp	Frame Alu(no insulation)
W16	Dbi clr3mm/13mm	Arg	upvc
W17	Dbi clr3mm/13mm	Arg	Frame Alu(insulation)
W18	Dbi clr3mm/13mm	Arg	Frame Alu(no insulation)
W19	Dbi clr6mm/6mm	Arg/air95/5	upvc
W20	Dbi clr6mm/6mm	Arg/air95/5	Frame Alu(insulation)
W21	Dbi clr6mm/6mm	Arg/air95/5	Frame Alu(no insulation)
W22	Dbi clr6mm/6mm	Kryp	upvc
W23	Dbi clr6mm/6mm	Kryp	Frame Alu(insulation)
W24	Dbi clr6mm/6mm	Kryp	Frame Alu(no insulation)
W25	Dbi clr6mm/6mm	Arg	upvc
W26	Dbi clr6mm/6mm	Arg	Frame Alu(insulation)
W27	Dbi clr6mm/6mm	Arg	Frame Alu(no insulation)

By modeling and simulating the 27 states mentioned in Table No. 1, the amount of heating and cooling load of each state has been determined in the Design Builder software. Diagrams 1 and 2 show the amount of heating and cooling load and diagram 3 shows the sum of heating and cooling loads.

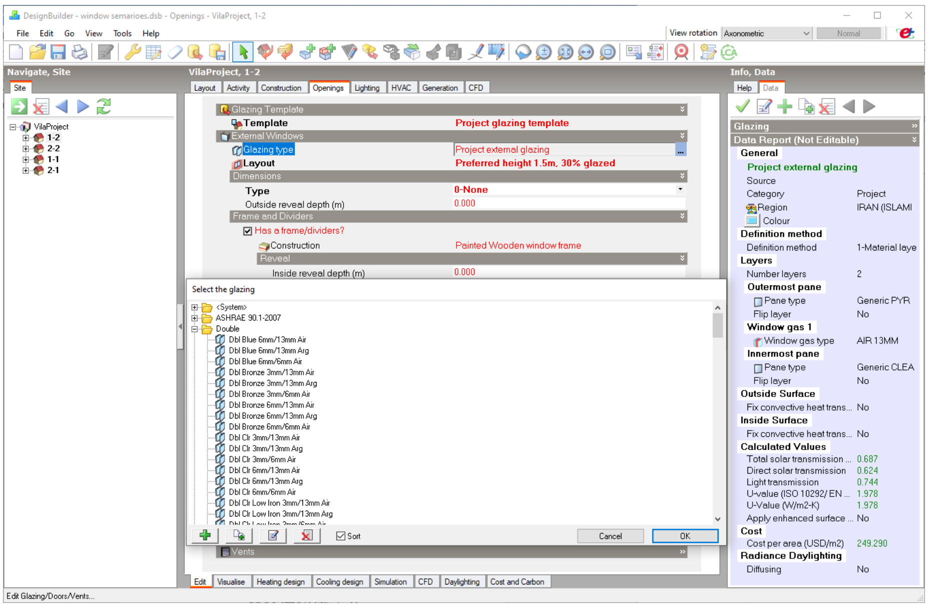

Figure 2: Defining and selecting different material modes for windows in the Design Builder software environment

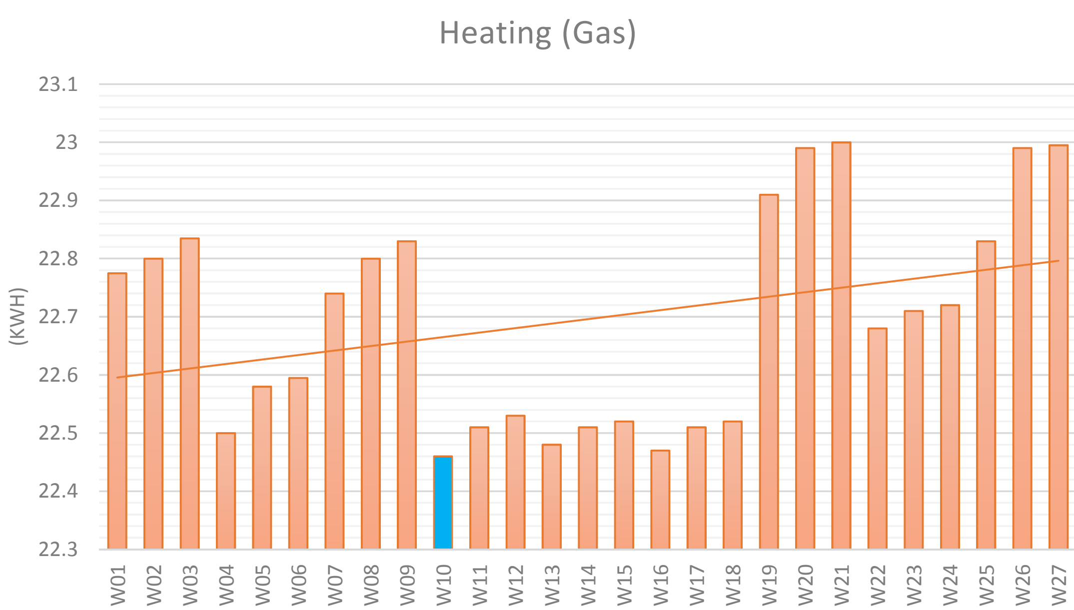

Diagram 1: Comparison of the amount of cooling load in the evaluated windows

According to the results of the evaluation that we can see in diagram 1, the amount of heating load in the use of different modes is compared. The worst options that have the highest amount of heating load in the evaluation results include 4 options W20, W2, W26 and W27, and these options cause more heating load in the building with a clear difference. The results show that nearly half of the evaluated modes have obtained favorable results regarding the amount of heating load. Therefore, among these items, the W10 window has the best condition, i.e. the lowest amount of heating load, in the evaluation.

Comparing the amount of cooling load shown in diagram number 2 shows that more than two-thirds of the evaluated cases out of the 27 types of openings studied cause a large amount of cooling load in the building. Among nearly 9 items with lower cooling load, the 25th type with the lowest cooling load with two 6 mm glasses with a distance of 6 mm, argon gas and UPVC frame has the best efficiency in eval-

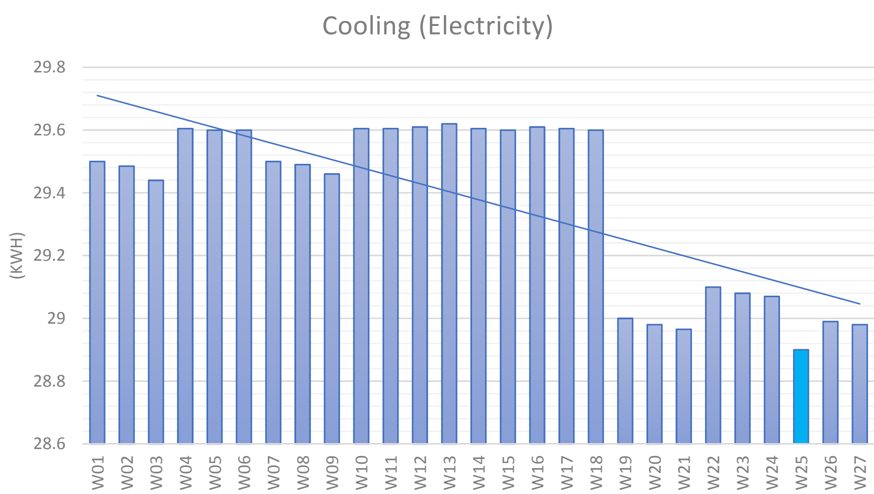

Diagram 2: Comparison of the amount of cooling load in the evaluated windows

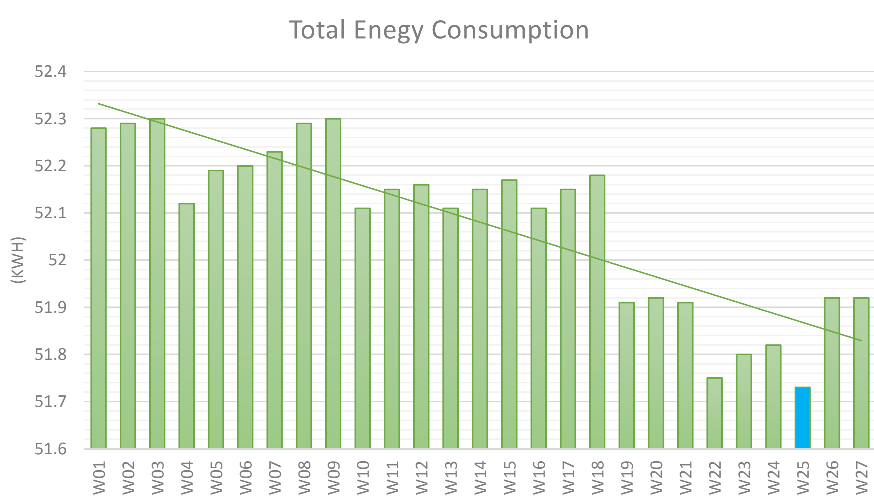

Diagram 3: Comparing the results of total thermal and cooling loads in the evaluated windows

uating the cooling load between the windows. . Since it is not possible to determine the type of window used by relying on one of the thermal and cooling tests, therefore, the total thermal and cooling loads in the evaluated windows have been discussed in diagram number 3 of the comparison, and the case with the lowest amount of load in total It has the total and is selected as the optimal option.

According to the energy simulation graphs of the total amount of heating and cooling consumption, it can be concluded that the W25 state is the most optimal state of energy consumption when the upvc frame and 6 mm double-glazed glass with argon gas are used. But it should be noted that the optimal state occurs when the three factors of cooling loads, heating and the use of daylight are considered together. In this regard, due to the fact that there is no great difference between the different types of gases used in windows in the field of using daylight, it can be concluded that the best way to use in the design of office buildings in order to optimize energy consumption is to use frames. Upvc and 6 mm double-glazed windows with argon gas.

Table 2: Different window dimensions

Opening Type	Aspect ratio	Glass used	Gas used	The type of frame used
A	1X1	Dbi clr 6mm/6mm	Arg	upvc
B	1.5X2	Dbi clr 6mm/6mm	Arg	upvc
C	2X2	Dbi clr 6mm/6mm	Arg	upvc
D	2X3	Dbi clr 6mm/6mm	Arg	upvc

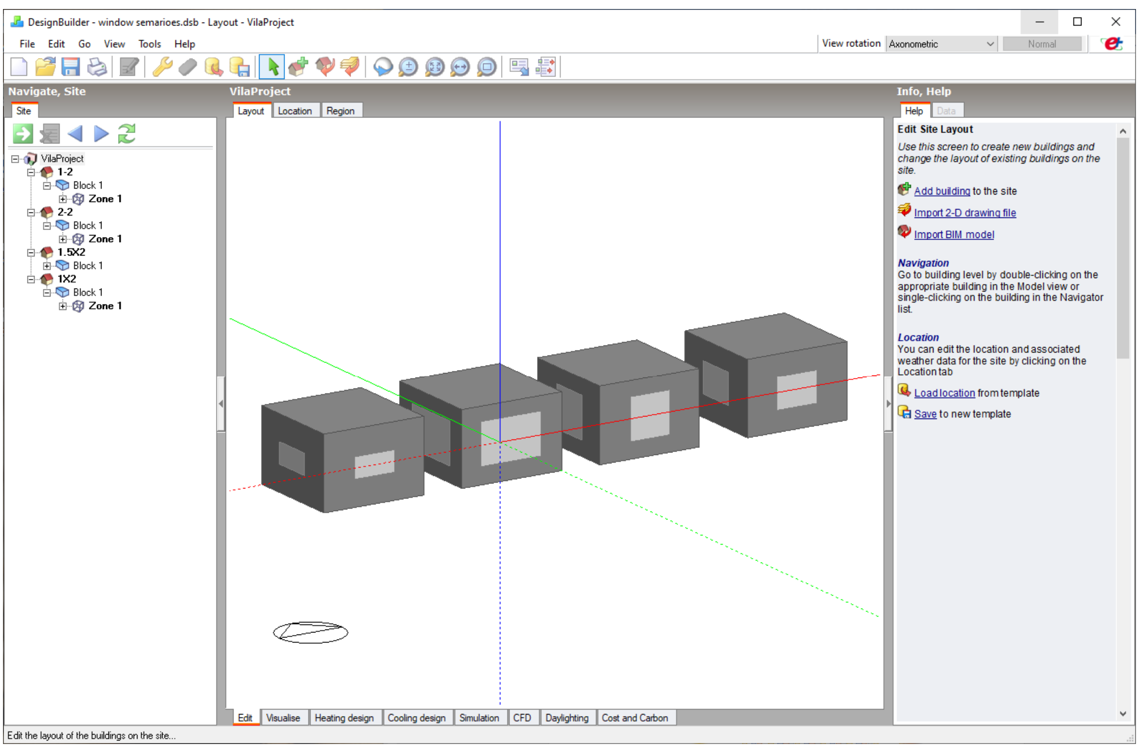

Figure 3: Modeling of selected dimension modes for openings

Window dimensions

After checking the best type of window to be used in the building, the most suitable ratio of the dimensions of the windows in the design has been evaluated. In this regard, a double-glazed window with a thickness of 6 mm using upvc frame and argon gas was selected as a sample in a building room, and this window was modeled with the dimensions of 1 in 1, 1 in 2, 2 in 1 and 2 in 2 and similar to Construction has been done in 4 modes. Table No. 2 shows the mentioned four modes for the dimensions of the windows.

In this episode; Chart No. 4, showing the comparison of the monthly average cooling load, Chart No. 5, comparing the monthly average heating load, Chart No. 6, comparing the results of the total thermal and cooling loads in the selected dimensions of the window, Chart No. 7, comparing the monthly average lighting load And chart number 8 compares the average monthly temperature of the indoor environment in selected dimensions of the window. To choose the best case from the proposed dimensions, it is necessary that the cooling and heating loads and the amount of energy required for lighting all three are included and their overall result determines the optimal dimensions for the openings in the design.

FINDING AND RESULTS

Examining graph 4, which shows the comparison of the monthly average cooling load in the dimensions selected for four types of windows, shows that the highest cooling load is observed in type D and size 2.3, which is the largest opening size in the four options selected for evaluation, and naturally It leads to more cooling load. Types A and B, which indicate the dimensions of 1.5 x 2 and 1 x 2, show almost the same values in comparison of the average cooling load. Among these, the best result belongs to type C with dimensions of 2 x 2, which has the lowest amount of cooling load. Chart No. 5 shows the comparison of the average monthly heating load between the 4 selected sizes. As it is clear in this diagram, the minimum amount of heating load in the building will be using 2 x 3 dimensions for openings. Also, like the assessment of the cooling load, the dimensions 1.5 x 2 and 1 x 2 show an average and almost identical amount in the average monthly heating load consumed by the building. The highest amount of heating load belongs to the 2 x 2 openings. As explained at the beginning of the evaluation, which of the parameters

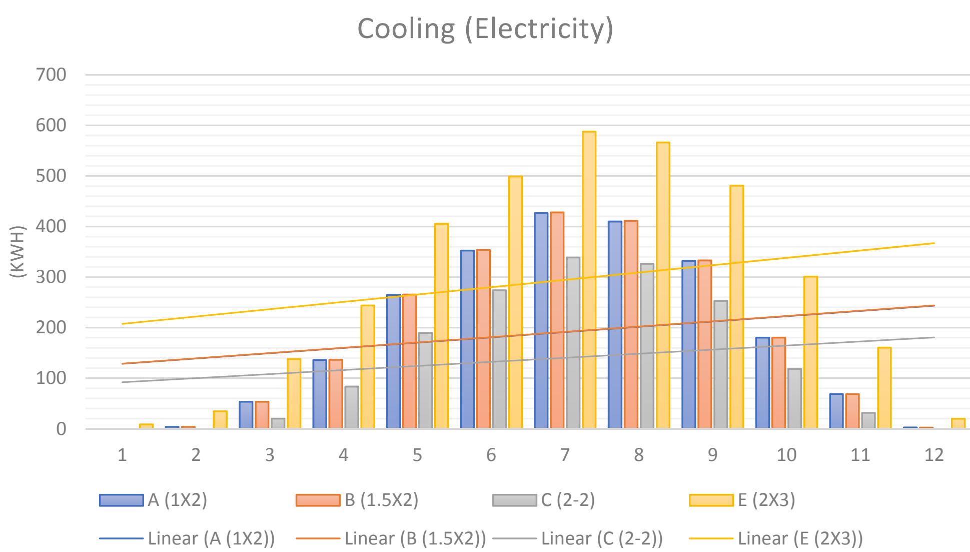

Diagram 4: Comparison of the average monthly cooling load in selected window dimensions

Alone, they cannot determine the optimal state of the opening size in order to consider the best state of energy consumption, it is necessary to examine the overall energy consumption process affected by the heating and cooling loads in the building, as well as the amount of energy required for lighting in choosing the best state of dimensions. The opening should be interfered with.

Examining the process of total thermal and cooling loads in the openings shown in diagram 6, it is clear that if 2x3 dimensions are used, we will have the highest amount of energy consumption in the building. Also, two sizes of 1 x 2 and 1.5 x 2 will achieve average consumption compared to other cases and almost the same. Based on the results of the set of consumption loads, it can be said that the best dimensions selected in the design of the building in this project will be 2 x 2 dimensions. Because in comparison, the result of the set of consumption loads of these dimensions of the opening has been assigned the lowest amount. At this stage, the amount of lighting load needs to be evaluated and the results obtained from it should be combined with the results of thermal and cooling consumption loads.

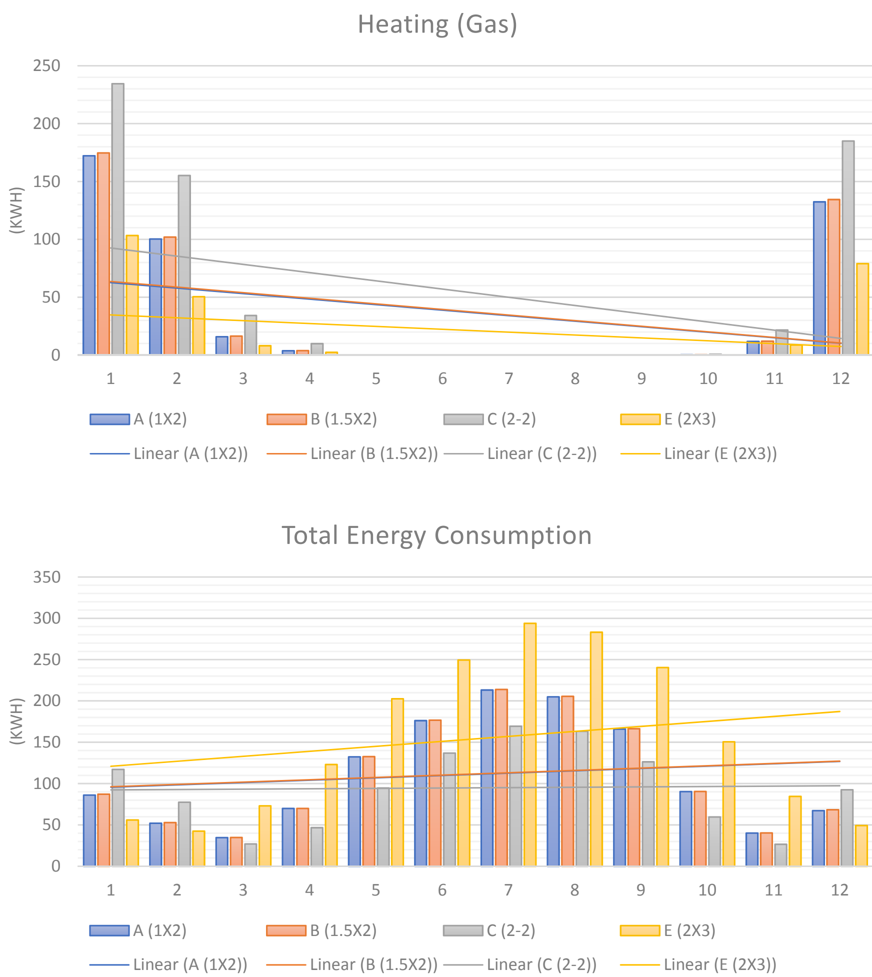

Chart 5: Comparison of the average monthly cooling load in the selected dimensions of the window

The study of graph 7, which shows the comparison of the monthly average lighting load in the selected dimensions of the windows, shows that, except for the first case, the sizes 1 x 2, which creates a slight difference in the lighting load of the building and increases it. The other three cases, which include the sizes of 1.5 x 2, 2 x 2 and 2 x 3, show almost constant values of the average monthly consumption of the lighting load in the building as a result of the simulation. Therefore, on this basis, the influence of the lighting load in the selection of window dimensions can be ignored, since the selected mode does not significantly differ from other modes in terms of lighting load, including cooling and thermal loads.

Finally, in order to pay attention to the closeness of the internal temperature in the range of thermal comfort and to confirm the selection of the optimal dimensions of the opening, we examine the results of the average temperature of the internal environment resulting from the evaluation of 4 opening modes. According to diagram number 8, the opening with dimensions of 2 x 3, considering that it brings more heat transfer due to radiation. It will cause a higher internal temperature. Meanwhile, the lowest temperature, which is the closest value to the thermal comfort range, will be possible using 2 x 2 dimensions. Therefore, the examination of this parameter is an emphasis on the optimality of mode C with dimensions of 2 x 2 for openings in this project.

DISSCUSION AND CONCLUSION

In this part, we will simulate the designed building in a general way until the amount of energy consumption of the whole building, of course, with the assumption of full use of all the spaces without preference and difference in thermal volume and homogenization of all the spaces of the building. At first, the overall 3D model is designed in the software space. The material of the surrounding walls is assumed based on the Ashera 55 standard, which can be accessed in the Design Builder software library, and the dimensions and material of the openings are based on the results of the previous stages of simulation, in the form of openings with dimensions of 2 x 2, upvc profile, argon gas and a distance of 6 The millimeter between the 6 mm walls is modeled. The simulation has been done for a period of one year and average monthly consumption.

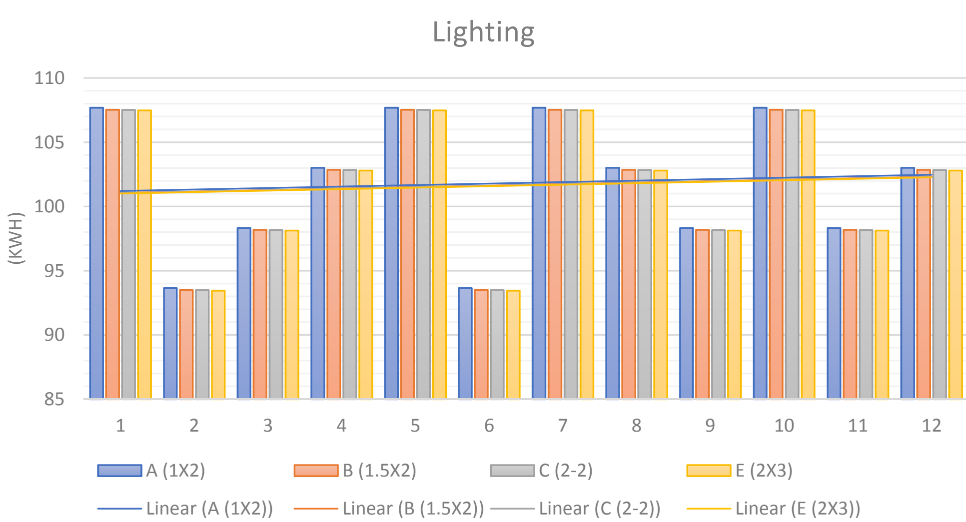

Chart 7: Comparison of the average monthly lighting load in selected window dimensions

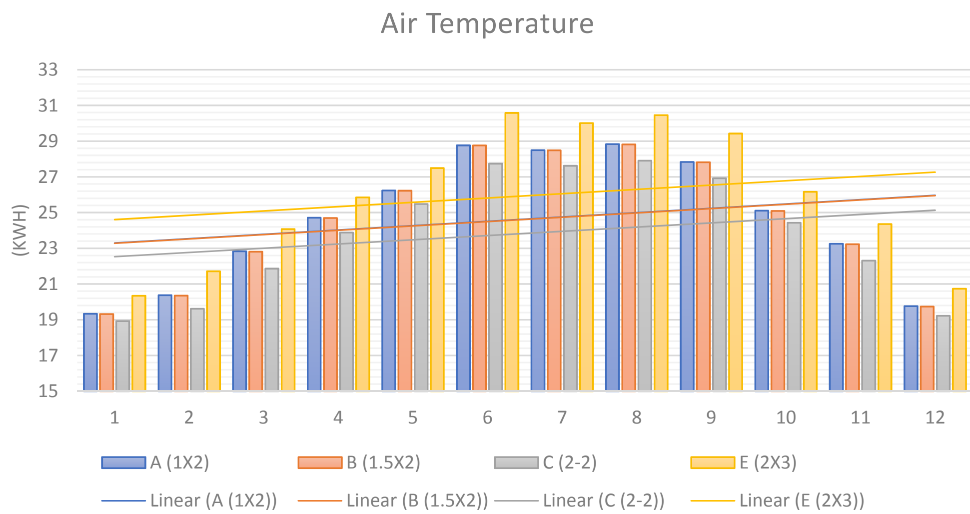

Chart 8: Comparison of the average monthly indoor temperature in selected window dimensions

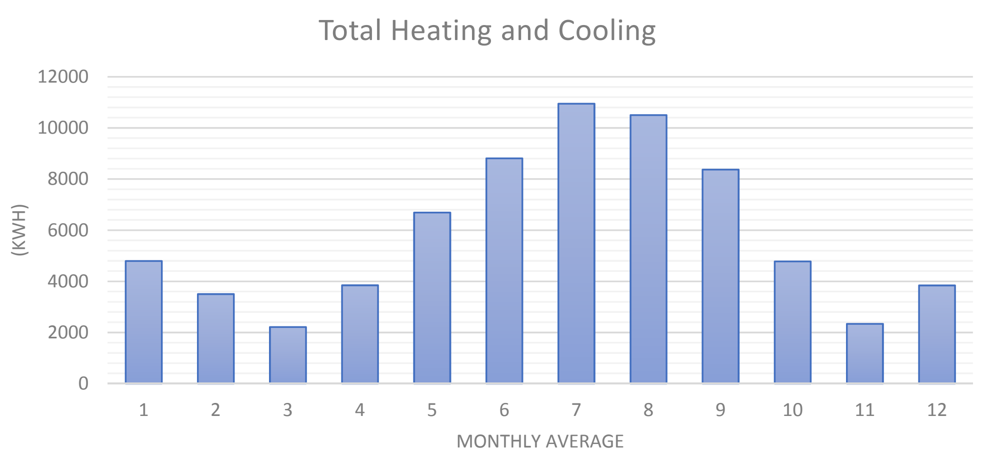

Diagram 9: Graphs of heat, temperature, thermal receipts and the amount of energy consumed from the direct output of Design Builder software.

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