ABSTRACT
Windows play a major role in the amount of energy consumption of buildings. This paper studies the effect of window area and shading devices on the energy consumption of office buildings in the climatic condition of Tehran region. Simulation is used for calculating the heating, cooling and lighting energy consumption of office buildings with different window area. The simulated buildings have the same constructional and architectural characteristics and differ only in the window area and the type of shading devices. Comparison of the amount of energy consumption of buildings shows the behaviour of energy consumption of office buildings regarding the window area and shading devices.

INTRODUCTION
Building energy simulation plays a decisive role in research on energy efficiency in buildings. Building energy simulation is a powerful analytical method for building energy research and evaluation of architectural design (Hensen et al. 1993, pp.17-23, Seth 1989, pp.240-247) and it is also a cost and time saving device. It aims to imitate the real physical conditions in a building by creating a mathematical model that represents all energy flow paths in a building as well as their interactions (Rizos 2007, p.16).

Simulation can be used for evaluation of buildings from the viewpoint of energy efficiency as well as optimization of energy performance of buildings.

This paper uses simulation for calculating the energy consumption of buildings in order to optimize their energy performance. One of the most important methods for optimization of energy performance of buildings is an analytical evaluative process, which deals separately with different architectural factors including orientation, opening orientation and ratio, sun shading etc. and also with constructional factors and elements such as air change rate, thermal mass, insulation material, etc. Because windows and shading devices are the key factors in building energy performance, among all architectural factors, this paper deals with window area and the type of shading devices. It studied the effect of window area in different orientations on the energy consumption of office buildings. It searches for the optimal window area and the most appropriate application of this building element under different conditions. An analysis of the simulations shows the behavior of energy efficiency of office buildings in relation to window area. Simulation with a developed dynamic simulation software tools is used in this research to accurately calculate the energy consumption of office buildings. Hourly weather data of Hashtgerd New Town, as research area, is also used to define external conditions during simulations.

Hashtgerd New Town is a small city in Tehran province, which is located 60km west of Tehran, north of the Tehran-Qazvin highway.

This new town is located in the “warm and dry” climatic region of Iran and has a cold winter and a warm and dry summer. The following graph shows the monthly average dry-bulb temperature of Hashtgerd in comparison with that of the coldest and warmest cities of Iran.

![Air temperature boundary in Iran and in Hashtgerd](source: Based on data from Iran Meteorological Organization, 2009)
To do that, different office buildings differing in window area are simulated with different variants for the given factor. Comparison of the amount of energy consumption of the building and also analyzing of the results leads to the optimal measures for windows for office buildings in the climatic condition of Hashtgerd. A 3-floor cell office building was designed to be used as reference for simulations and analysis.

DesignBuilder is used for simulation of buildings. DesignBuilder is the first comprehensive user interface to the EnergyPlus dynamic thermal simulation engine. It combines rapid building modeling and ease of use with state of the art dynamic energy simulation. This program analyses the effects of design alternatives on key design parameters such as: annual energy consumption, overheating hours, and CO2 emissions (DesignBuilder Software Ltd 10.05.2008)

**WINDOW**

Window area in different orientations excessively affects the energy consumption of buildings and is one of the most important factors for architectural energy efficiency.

In order to find the optimum window ratio from the viewpoint of energy efficiency, different office buildings are simulated. These buildings, which oriented to south and elongated in the east-west axis, have the same window/wall ratio in all orientations. These buildings are simulated under the same (climatic, constructional and architectural) conditions and all characteristics of these buildings except window area are the same. For minimizing the effects of the characteristics of thermal envelop on the results, the U-values of the components of thermal envelope of all buildings are the same. The hot water radiator is used for heating of these buildings and chiller for cooling of these buildings. All characteristics of heating and cooling systems are the same in all buildings. In these buildings, the amount of energy consumed for heating, cooling and lighting is considered.

**Windows without Shading Devices**

In order to find the optimum window area for office buildings, 11 buildings with different window/wall ratio are simulated. The window/wall ratio is the same in all orientations. The windows have no shading devices.

The following graph shows the heating, cooling, lighting and total energy consumption of this office building with different window ration.

The following results can be derived from the above graph regarding heating, cooling, lighting and total energy consumption of office buildings:

**Heating Energy Consumption**

The heating energy consumption of office buildings decrease by increasing the window area from 10 to 80% window/wall ratio.

Increasing the window to wall ration from 80 to 100% will increase a bit the heating energy consumption.

**Cooling Energy Consumption**

The cooling energy consumption of office buildings increase by increasing the window area from 10 to 100% window/wall ratio.

**Lighting Energy Consumption**

Increasing the window area of the office building from 0 to 100% window/wall will reduce the energy demand for lighting. But reduction of lighting energy consumption is very high from 0% to 30% window/wall area. After 30% the lighting energy consumption will be decreased very slowly. Especially after 40% window ration the reduction of lighting energy consumption is very little, which can be renounceable (connived). That means from the viewpoint of energy efficiency, 30% window/wall ratio is the optimal ration when only lighting is concerned.

**Total Energy Consumption**

Increasing the window area from 0 to 50% window/wall ratio will decrease the total energy consumption of office buildings. But increasing the window area in all orientations from 50% to 100% window to wall area increases the total energy consumption.

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1 - The U-value of the components of the thermal envelope of all simulated office buildings are as following:

Exterior Wall: 1.02 W/m²K - Roof: 0.44 W/ m²K - Floor (adjacent to earth): 2.12 W/ m²K – Floor: 2.12 W/ m²K – Floor: 2.12 W/ m²K – Floor: 2.12 W/ m²K – Floor: 2.12 W/ m²K – Floor: 2.12 W/ m²K – Floor: 2.12 W/ m²K – Floor: 2.12 W/ m²K – Floor: 2.12 W/ m²K – Floor: 2.12 W/ m²K – Floor: 2.12 W/ m²K – Floor: 2.12 W/ m²K – Floor: 2.12 W/ m²K – Exterior Door: 5.11 W/ m²K - Interior Wall (adjacent to uncontrolled Space): 0.8W/ m²K.
consumption. It shows that, if the windows have no shading devices, the optimum window ratio for office buildings, which have the same window to wall ratio, is 50%.

Windows with External Blind

The following graph shows the heating, cooling, lighting and total energy consumption of an office building with different window ratio. The window/wall ratio is the same in all orientations. The windows of these buildings have external blinds.

The following results can be derived from the above graph regarding heating, cooling, lighting and total energy consumption:

Heating Energy Consumption

Increasing the window area from 0 to 20% window/wall ratio will increase the heating energy consumption of office buildings.

Increasing the window to wall ratio from 20 to 80% decreases the heating energy demand of office buildings.

Increasing the window to wall ratio from 80 to 100% will increase a bit the heating energy consumption.

Cooling Energy Consumption

The cooling energy consumption of office buildings increases with the increasing the north-facing window area.

The cooling energy demand of the office building will decrease from 0 to 20% window/wall ratio. But increasing the window area over 20% will increase the cooling energy demand. The effect of the north-facing window area on cooling energy consumption of office buildings is very low.

Lighting Energy Consumption

Increasing the north-facing windows decreases the lighting energy consumption of office buildings. But decreasing the lighting energy consumption after 20 and 30% is very low.

Total Energy Consumption

Increasing the window area from 0 to 50% window/wall ratio in all orientations will decrease the total energy consumption of office buildings in Hashtgerd. But increasing the window area from 50% to 100% window to wall area increases the total energy consumption. Therefore, the optimum window ratio for office buildings with the same window to wall ratio in all orientation is 50%.

North-Facing Windows

Last simulations has shown that, 60% window ratio in all orientations is the optimum window area for total energy consumption of buildings. But to find the optimum window ratio separately for every of four orientations, different office buildings with 60% south, east and west-facing window ratio and various north-facing window ratio are simulated.

This graph presents the energy consumption of this office building with different north-facing window area and 60% south, east and west-facing window area.

These results can be derived from the above graph regarding heating, cooling, lighting and total energy consumption of office buildings.

Heating Energy Consumption

The heating energy consumption of office building increases with the increasing the north-facing window area.

Cooling Energy Consumption

The cooling energy demand of the office building will decrease from 0 to 20% window/wall ratio. But increasing the window area over 20% will increase the cooling energy demand. The effect of the north-facing window area on cooling energy consumption of office buildings is very low.

Lighting Energy Consumption

Increasing the north-facing windows decreases the lighting energy consumption of office buildings. But decreasing the lighting energy consumption after 20 and 30% is very low.
**Total Energy Consumption**

The sum of heating, cooling and lighting energy consumption of office buildings will decrease with increasing the north-facing window ratio from 0 to 20% window area to wall area. Increasing the north-facing window area over 20% increases the total energy consumption of office buildings. That shows that the optimum window area for north-facing façade is 20% and can be increased up to 30%.

**East and West-Facing Windows**

Last simulations has shown that, 60% window ratio in south-facing façade and 20% window in north-facing one are the optimum window area regarding total energy consumption of buildings. In order to find the optimum window ratio for east and west orientations, different office buildings with 60% south-facing windows and 20% north-facing windows and various east and west-facing window ratio are simulated.

The following graph presents the results of these simulations.

![Figure 5](image)

This graph proves that the behavior of office buildings regarding the area of east/west-facing windows is as follow:

**Heating Energy Consumption**

The heating energy consumption of office building decreases with the increasing the east and west-facing window area. That is because the building can have solar gain from both east and west-facing windows in winter.

**Cooling Energy Consumption**

The cooling energy demand of the office building increases by increasing the east and west facing windows. The east and west-facing windows have very high solar gain in summer. Solar gain of east and west-facing windows in summer is also much more than of that in winter. Therefore east and west-facing windows are weakness of buildings from the viewpoint of energy efficiency and especially for cooling.

**Lighting Energy Consumption**

Increasing the east and west-facing windows decreases the lighting energy consumption of office buildings. The effect of east and west-facing windows on lighting energy is very low.

**Total Energy Consumption**

The sum of heating, cooling and lighting energy consumption of office buildings increases by increasing the north-facing window ratio, however the building with 10% east and west-facing window is very little more than the building with no east and west-facing windows. For this reason and because of importance of daylighting, the optimum window ratio for east and west-facing facades is 10%.

**SHADING DEVICES**

**Overhang**

In order to find the effect of overhangs and their projection size on energy consumption of office buildings in Hashtgerd, an office building with different overhang projection size are simulated. The windows in all orientations have similar overhangs with the same projection size.

This graph shows the heating, cooling, lighting and total energy consumption of an office building with overhangs with different projection size.

![Figure 6](image)

Comparison of the energy consumption of these buildings shows that:

Having overhang and increasing the projection size of overhangs will increase the heating energy demand of office buildings in Hashtgerd.

Having and increasing the projection size of overhands will reduce the cooling energy consumption of office buildings.

Overhangs increase the lighting energy consumption of office buildings in Hashtgerd.
The increase of heating energy consumption by overhangs with different projection sizes is more than reducing the cooling energy demand of the building. The decrease of cooling energy demand is approximately equal with the increase of lighting energy demand.

Therefore, using overhang for windows of office buildings in all orientations and also increase of the projection size of overhangs will increase their total energy consumption.

High solar altitude in Hashtgerd especially in summer and short work time of office buildings in Iran (and Hashtgerd) and situation of a big part of work time before noon, are the most reasons for little effect of shading devices on energy consumption of office buildings in Hashtgerd.

**External Blind**

In order to study the effect of external blinds and the type of controlling them on energy consumption of office buildings in Hashtgerd, an office building without any shading devices and with external blind with different type of controlling the blinds are simulated. Comparison of the heating, cooling, lighting and total energy consumption of this office building with and without external blinds shows that the external blinds and type of controlling them will affect heating, cooling, lighting and total energy consumption of office buildings.

This graph presents the energy consumption of the simulated buildings.

![Graph showing energy consumption of office building with different control types of external blinds](image)

The following results can be derived from this graph.

**Heating Energy Consumption**

The heating energy consumption of office buildings will change according to the control type of external blind. External blinds will reduce the heating energy consumption of building in comparison with not having any blind, if they are controlled according to: "outside air temperature", "day cooling and solar and night", "night outside low air temperature", "night inside low air temperature", "night heating" and "night outside low air temperature and day cooling".

Because closing the blinds in the winter nights will reduce the heat loss through long wave radiations, the controlling types reducing the heating energy demand, relates to night controlling.

**Cooling Energy Consumption**

External blinds decrease the cooling energy consumption of office building with many types of controlling. They increase very low the cooling energy consumption, if they are controlled according to "Outside air temperature", "Night outside low air temperature", "Night heating" and "Night inside low air temperature".

**Lighting Energy Consumption**

External blinds increase the lighting energy consumption of office buildings except when they are controlled according to "Daylight", "Night outside low air temperature", "Night heating" and "Night inside low air temperature".

**Total Energy Consumption**

The external blinds reduce the sum of heating, cooling and lighting energy consumption of office buildings, only if they are controlled according to "Night outside low air temperature", "Night heating" and "Night inside low air temperature".

If the external blinds are controlled according these control types, both heating and lighting energy consumption of office building will be decreased. However, the cooling energy consumption will increase a little.

The effect of external blind on decreasing the total energy consumption of office building is generally very little. High solar altitude in Hashtgerd especially in summer and short work time of office buildings in Iran (and Hashtgerd) and situation of a big part of work time before noon, are the most reasons for little effect of shading devices on energy consumption of office buildings in Hashtgerd.

**CONCLUSION**

This paper has shown that, the window area in different orientations and also the type of shading devices effectively influence the heating, cooling, lighting and total energy consumption of office buildings. The results show the thermal behavior of office buildings regarding window area and shading devices. A short summary of the results are as following:

- For buildings with the same window ratio without shading devices in all orientation, the optimum...
window ratio for heating, cooling and lighting is respectively 80%, 10% and 40%. For reduction of total energy consumption the optimum window to wall ratio is 50%.

- The behavior of buildings with external blinds is a bit different in comparison with buildings without shading devices. For buildings with external blinds, the optimum window ratio for heating, cooling and lighting is respectively 80%, 10% and 50%. For reduction of total energy consumption the optimum window to wall ratio is 60%.

- For buildings with different window ratio in different orientations, the optimum window ratio for south-facing, north-facing and east/west-facing facade is respectively 60%, 20-30% and 10%.

- Using overhang for windows of office buildings in all orientations and also increase of the projection size of overhangs will increase their total energy consumption. However, it decreases a bit the cooling energy consumption of office buildings.

- The type of controlling the external blinds is the key factor for the effect of this type of shading devices on energy consumption of office buildings in Hashtgerd.

REFERENCES


